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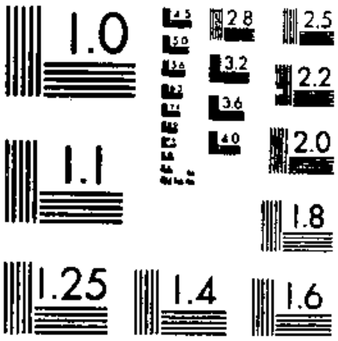

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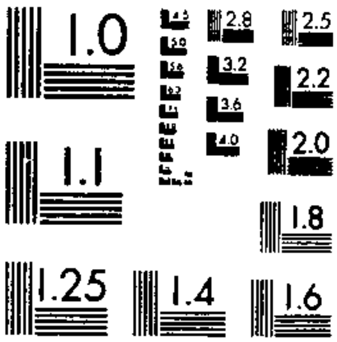

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Decomposition of WOOD and BARK SAWDUSTS in SOIL, NITROGEN REQUIREMENTS, and EFFECTS ON PLANTS

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DECOMPOSITION OF WOOD AND BARK SAWDUSTS IN SOIL, NITROGEN REQUIREMENTS, AND EFFECTS ON PLANTS

By Franklin E. Allison, *soil scientist, Soil and Water Conservation Research Division, Agricultural Research Service* [1]

INTRODUCTION

Numerous publications, mostly of a popular nature, that discuss the use of sawdusts for soil improvement and mulches have appeared in print during the past 20 years. Many of these deal, in a general way, with the use and benefits of sawdusts without reference to any particular wood species. Even where original research has been reported, the kind of wood used is often not mentioned. Seldom is a comparison of the behavior of different kinds of woods reported, or the comparative responses of woods and barks shown. Accurate data on the quantities of nitrogen immobilized by the micro-organisms responsible for decomposition are few, or nonexistent, for most tree species. Likewise, the evidence for or against toxic effects of various woods and barks on plants is inadequate.

The present bulletin reports extensive studies of the rates of decomposition in soil of the woods and barks of a large number of tree species, the quantities of nitrogen required for their decomposition, and the effects of these woods and barks on the germination and early growth of garden peas. Although most of the data presented in this bulletin have been published elsewhere (*2*, *3*, *4*, *6*, *7*, *8*),[2] there are obvious advantages in having this information assembled in a single publication.

SOME FACTORS THAT AFFECT THE RATE OF DECOMPOSITION

Materials and Methods

Shortleaf pine (*Pinus echinata*) sawdust was used in the initial experiments on factors that affect the rate of decomposition. It contained 0.13 percent N and 45.0 percent C on an air-dry basis.

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[1] The author is indebted to R. M. Murphy, C. J. Klein, R. G. Cover, W. H. DeMar, and J. H. Smith of the Soil and Water Conservation Research Division for conducting portions of the laboratory and greenhouse investigations reported here.

[2] Italic numbers in parentheses refer to "Literature Cited," p. 30.

Chester loam surface soil from Maryland, which had not been cropped recently, was used for the experiment on sawdust particle size. It contained 0.122 percent N and 1.42 percent C, and had a pH of 5.5. It was sieved through a 10-mesh sieve, air dried, and stored for use as needed. Branchville sandy loam surface soil, which had been under cultivation for several years, was used in the experiments dealing with nitrogen level and sources, and with lime. It contained 0.057 percent N, 0.84 percent C, and had an initial pH of 5.4. This soil was sieved through a 10-mesh sieve, leached thoroughly with water to remove all nitrates, air dried, and stored until needed.

The experiments were conducted in duplicate in 500-ml. bottles having standard taper necks fitted with inlet and outlet tubes for aeration. To each bottle were added 50 grams of air-dry soil, 1 percent air-dray sawdust, and a fertilizer mixture. The sawdust used, except in the experiments on particle size, was the portion that, after being ground in a Wiley mill, passed through a 6-mesh sieve. The fertilizer mixture consisted of superphosphate, potassium sulfate, calcium sulfate, and magnesium sulfate in amounts such as to supply 300 pounds of P_2O_5, 200 pounds of K_2O, 100 pounds of CaO, and 50 pounds of MgO per 2 million pounds of soil. Calcium hydroxide or calcium carbonate was also added in some tests. After the various ingredients were mixed with the soil, nitrogen was added in various forms and amounts as an aqueous solution. Distilled water was then added to bring the moisture to 65 percent of water-holding capacity; this was 23 percent moisture for the Chester loam and 14 percent for the Branchville soil. Three additional milliliters of water were added for each gram of sawdust used. Rubber tubes with clamps were fitted over the aeration tubes and the closed bottles were placed in a constant-temperature room (30° C.).

The bottles were removed from the 30° room at intervals and aerated with CO_2-free air that was saturated with water vapor. The stream of air leaving the bottles, containing CO_2, was passed through concentrated sulfuric acid, drierite, and ascarite. The increase in weight of the ascarite was a measure of the amount of CO_2 formed during the incubation period and a measure of the degree of decomposition. After each aeration, the bottles were closed by means of the clamps on the rubber tubes and returned to the constant-temperature room.

The time interval between successive aerations varied with the rate of evolution of CO_2. During the first 2 weeks of an experiment the bottles were usually aerated every 2 to 5 days, but after several weeks the interval was 3 weeks or longer. The intention was to aerate before the oxygen level had been reduced below 12 to 15 percent, but in a few instances lower concentrations existed for short periods. Such temporary accumulation of CO_2 had little effect on total CO_2 release during a period of a few days or weeks. It was observed that even when the soil-sawdust mixtures were not aerated until most of the oxygen was used up, an increased rate of CO_2 evolution usually occurred following aeration. The data reported are, with minor exceptions, the averages of duplicate determinations.

Experimental Results

Effect of Sawdust Particle Size

The rates of decomposition of shortleaf pine wood particles of three sizes in Chester loam are shown in figure 1. In this experiment, enough ammonium nitrate was added to raise the nitrogen content of the sawdust to 2.0 percent. The CO_2 evolution from the soil without sawdust is also shown.

CO_2 evolution during the first 30 days increased significantly with fineness of division of the particles, but subsequently all of the particles that were six mesh and smaller decomposed at similar rates. The rates of decomposition of a 20- to 40-mesh sample and also one that passed through 40 mesh, which are not shown here, were slightly greater initially than the rates for the 10- to 20-mesh sample. After about 2 weeks, however, the differences were within experimental error. A 10- to 20-mesh sample that was merely distributed over the soil surface released CO_2 initially at the same rate as the 4- to 6-mesh fraction that was mixed with the soil; later the rate of release increased to such an extent that at the end of the experiment the total release was the same as from the 10- to 20-mesh sample that was incorporated in the soil. Such a result would not be expected in a less humid atmosphere.

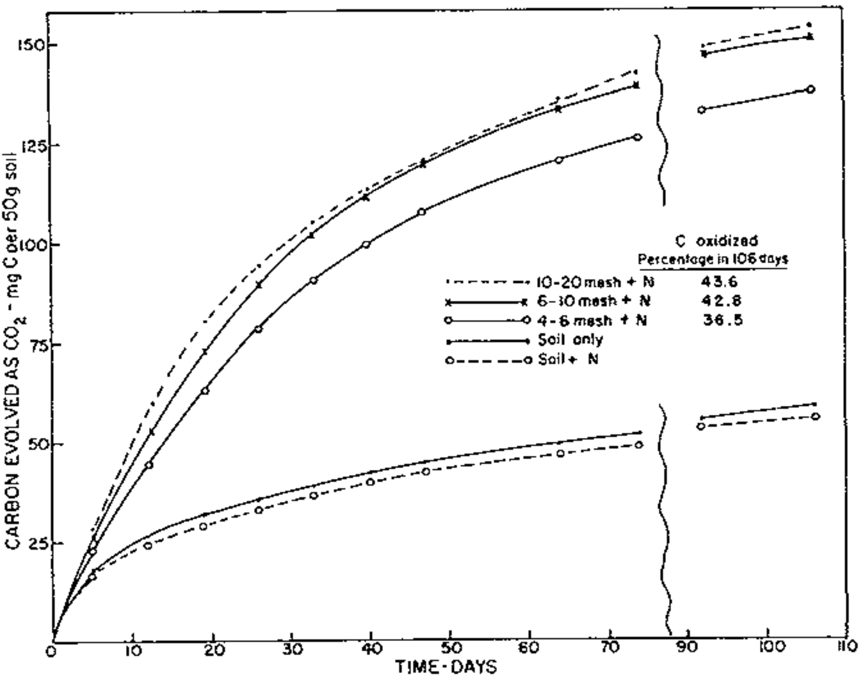

FIGURE 1.—Effect of size of wood particles on rate of decomposition of shortleaf pine sawdust in soil.

The carbon evolved as CO_2 from the shortleaf pine sawdust, six mesh and smaller, amounted to approximately 32 percent in 40 days, and 43 percent in 106 days. (See fig. 1.) These values are somewhat below those for a material such as wheat straw (*2*, *19*) but greater than for most other woods, as will be shown later.

Effect of Nitrogen Level

The effect of four levels of nitrogen on the decomposition of shortleaf pine sawdust is shown in figure 2. The nitrogen levels, based on the weight of the dry wood, were made 0.13, 0.5, 1.0, and 2.0 percent by additions of ammonium nitrate. As stated above, the soil used was the water-leached Branchville sandy loam.

Additions of ammonium nitrate at rates up to 1 percent increased the rate of oxidation of the sawdust rather markedly during the first 2 months, but thereafter the accumulative CO_2 values tended to draw together. The 2-percent nitrogen rate caused some depression. It is evident from figure 2 that nitrogen at the 1-percent level was adequate for a maximum rate of decomposition. The additional unneeded nitrogen not only lowered the pH but also increased the salt concentration, which apparently either modified the microflora or reduced their activity.

Effect of Nitrogen Source and Level

The results of factorial experiment in which five nitrogen sources at five nitrogen levels were used, and CO_2 evolution determined during

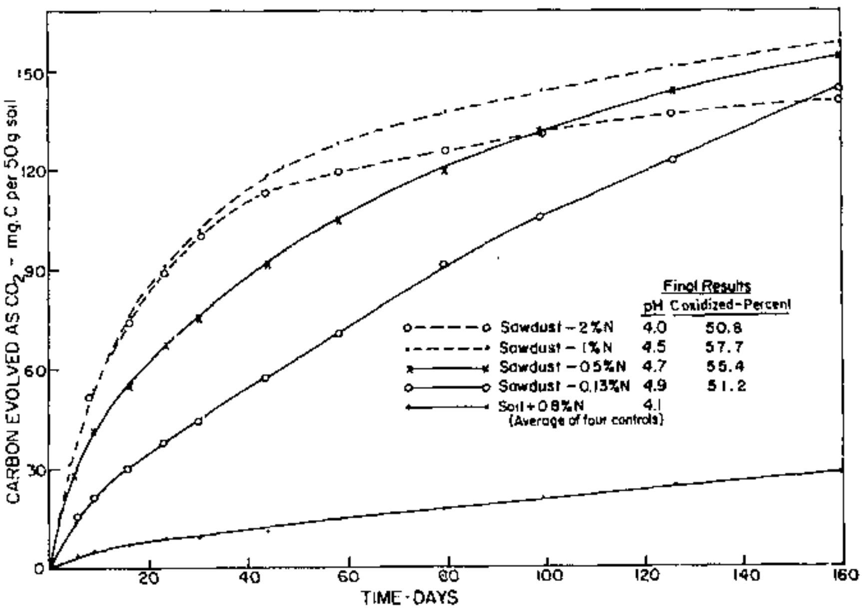

FIGURE 2.—Effect of nitrogen level on rate of decomposition of shortleaf pine sawdust in soil.

a period of 72 days, are reported in table 1. These studies were made in Branchville sandy loam using shortleaf pine sawdust. The total carbon that was released as CO_2 from sawdust in 72 days was obtained by subtracting control values for soil without sawdust (not shown except for the 0-percent nitrogen level) from the CO_2 values found for the sawdust-soil mixtures. Correction was made for the CO_2 released from urea.

An analysis of variance of the total CO_2-evolution values given in table 1 shows significance for both nitrogen sources and nitrogen rates at the 1-percent level of significance, but the interactions were not significant. The analysis shows further that sodium nitrate and calcium nitrate were equally good as nitrogen sources, and under the experimental conditions, were slightly better for sawdust decomposition than were ammonium nitrate, ammonium sulfate, or urea.

Table 1 also shows that when sufficient nitrogen in any of the five forms was added to bring the wood up to 0.75 percent nitrogen, decomposition proceeded at an essentially maximum rate. Larger additions either had no further effect on CO_2 evolution or slightly depressed it.

The data in the last column of table 1 show that sodium nitrate and calcium nitrate slightly increased the soil pH, whereas the other three nitrogen sources consistently lowered it. When the pH effect was removed by means of a covariance analysis, the effect of nitrogen rates was no longer significant, and that of nitrogen sources was barely significant at the 5-percent level. Nitrate nitrogen sources were, therefore, only slightly preferable to ammonia sources in this experiment.

Effect of Lime Source and Level

The effects of calcium hydroxide and calcium carbonate, at two levels, on the evolution of CO_2 from shortleaf pine in the Branchville soil are shown in table 2. Ammonium sulfate was added at nitrogen rates corresponding to 1.5 and 3.0 percent of the weight of the sawdust, and diammonium phosphate at the higher rate only. Controls without fertilizer nitrogen were also included. Where either calcium hydroxide or calcium carbonate was added in sufficient amounts to maintain the pH values at near neutral, these nitrogen sources were as satisfactory as were sodium nitrate and calcium nitrate in the experiments summarized in table 1.

Calcium hydroxide had little effect on CO_2 evolution from the soil alone without added nitrogen. Under similar conditions, except for the the addition of sawdust, calcium hydroxide increased CO_2 evolution by 25 percent at the low rate and 19 percent at the high rate. These increases were probably the result of the higher soil pH. However, at the higher rate of calcium hydroxide it is probable that some CO_2 was fixed as $CaCO_3$, thus accounting for the slightly lower CO_2 evolution values found.

TABLE 1.—*Effect of nitrogen source and level on the rate of decomposition of shortleaf pine wood sawdust in soil*

Treatments [1]	Carbon, evolved as CO_2, per 50 grams of soil incubated for—									C evolved as CO_2 from sawdust		Soil reaction after 72 days
	6 days	9 days	13 days	16 days	20 days	30 days	43 days	56 days	72 days	Total [2]	As percentage of added wood C	
0 PERCENT NITROGEN												
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*		*pH*
Control	5.0	7.3	8.9	10.2	11.1	13.5	16.0	17.9	20.1	------	------	5.3
Sawdust	18.5	27.7	34.9	40.2	45.1	58.6	70.1	79.9	89.6	69.5	30.9	5.6
0.75 PERCENT NITROGEN												
Sawdust plus—												
NH_4NO_3	31.9	50.3	64.4	73.8	80.3	95.6	108.4	117.5	12[illegible].7	106.3	47.2	5.6
$NaNO_3$	34.3	53.0	67.8	77.1	84.9	102.5	114.7	123.6	131.7	113.3	50.4	5.8
$(NH_4)_2SO_4$	30.2	44.9	61.3	72.6	82.5	96.5	109.9	119.1	127.9	107.8	47.9	5.3
$CO(NH_2)_2$	32.5	49.4	64.4	71.8	80.2	94.5	108.2	118.5	127.8	107.2	47.6	5.5
$Ca(NO_3)_2$	37.9	54.0	73.3	81.2	90.5	105.8	116.7	126.3	133.7	116.7	51.9	5.8
1.5 PERCENT NITROGEN												
Sawdust plus—												
NH_4NO_3	31.5	47.2	64.2	76.4	83.8	101.3	113.4	119.6	124.2	105.5	46.9	5.2
$NaNO_3$	34.1	52.0	71.1	81.9	89.4	107.7	119.8	126.2	131.2	114.5	50.9	5.8
$(NH_4)_2SO_4$	32.3	48.6	63.3	74.4	82.1	99.9	110.3	115.7	121.1	101.0	44.9	4.4
$CO(NH_2)_2$	31.6	48.8	67.3	79.2	87.6	99.8	112.7	119.8	125.2	104.4	46.4	5.1
$Ca(NO_3)_2$	34.9	52.1	72.9	81.4	89.1	103.5	113.5	121.9	127.4	113.6	50.5	5.8

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2.25 PERCENT NITROGEN

Sawdust plus—												
NH_4NO_3	32.9	47.7	65.9	72.7	82.1	94.5	106.2	111.5	115.0	98.7	43.9	4.9
$NaNO_3$	35.8	52.5	72.3	81.5	89.6	107.6	119.1	124.4	129.6	114.7	51.5	5.9
$(NH_4)_2SO_4$	35.7	50.3	67.9	75.6	85.1	99.4	107.5	112.8	117.8	99.2	44.1	4.1
$CO(NH_2)_2$	40.6	58.9	80.5	88.6	95.3	102.8	110.7	116.8	122.0	102.2	45.4	4.7
$Ca(NO_3)_2$	33.2	48.0	66.5	75.2	84.1	96.8	108.3	118.1	124.3	108.0	48.0	5.8

3.0 PERCENT NITROGEN

Sawdust plus—												
NH_4NO_3	31.2	45.9	63.5	70.2	79.3	91.8	101.1	109.3	112.1	98.2	43.6	4.4
$NaNO_3$	30.7	46.8	66.2	74.3	83.7	98.7	113.4	119.2	124.5	111.5	49.6	5.9
$(NH_4)_2SO_4$	33.5	48.0	65.4	73.0	82.1	96.5	105.2	110.4	115.4	98.4	43.7	4.2
$CO(NH_2)_2$	37.0	57.1	82.1	89.9	97.7	104.8	111.6	117.8	121.5	102.8	45.7	4.2
$Ca(NO_3)_2$	30.6	45.4	63.9	72.7	82.1	95.0	106.8	116.2	121.9	109.4	48.6	5.7

[1] NH_4NO_3 — Ammonium nitrate.
$NaNO_3$ — Sodium nitrate.
$(NH_4)_2SO_4$ — Ammonium sulfate.
$CO(NH_2)_2$ — Urea.
$Ca(NO_3)_2$ — Calcium nitrate.

[2] C evolved from sawdust-soil mixtures minus that evolved from controls (not shown except for 0 percent nitrogen), which did not receive sawdust.

TABLE 2.—*Effect of lime on the rate of decomposition of shortleaf pine wood sawdust in soil*

Treatments [1]	Carbon, evolved as CO_2, per 50 grams of soil incubated for—									C evolved as CO_2 from sawdust		Soil reaction after 72 days
	6 days	9 days	13 days	16 days	20 days	30 days	43 days	58 days	72 days	Total [2]	As percentage of added wood C	
UNLIMED												
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*		*pH*
Control	5.0	7.3	8.9	10.2	11.1	13.5	16.0	17.9	20.1			5.3
$(NH_4)_2SO_4$—1.5 pct. N	4.4	6.4	8.5	10.1	11.0	13.2	15.8	17.8	20.1			4.2
$(NH_4)_2SO_4$—3.0 pct. N	4.8	5.9	7.4	8.6	10.1	11.9	14.0	15.5	17.0			4.2
$(NH_4)_2HPO_4$—3.0 pct. N	6.2	9.2	11.4	12.4	13.5	16.0	18.5	19.9	21.6			4.6
Sawdust	18.5	27.7	34.9	40.2	45.1	53.6	70.1	79.9	89.6	69.5	30.9	5.6
Sawdust+$(NH_4)_2SO_4$—1.5 pct. N	32.3	48.6	63.3	74.4	82.1	99.9	110.3	115.7	121.1	101.0	44.9	4.4
Sawdust+$(NH_4)_2SO_4$—3.0 pct. N	33.5	48.0	65.4	73.0	82.1	96.5	105.2	110.4	115.4	98.4	43.7	4.2
Sawdust+$(NH_4)_2HPO_4$—3.0 pct. N	37.5	54.7	72.2	81.6	91.6	107.8	118.5	124.2	129.3	107.7	47.9	4.4
0.075 PERCENT CALCIUM HYDROXIDE												
Control	5.6	8.3	10.4	11.3	12.5	15.0	17.4	18.6	20.9			6.8
Sawdust	23.8	34.6	44.2	50.9	59.3	73.0	85.0	95.7	107.7	86.8	38.6	6.9
Sawdust+$(NH_4)_2SO_4$—1.5 pct. N	40.2	60.5	78.0	85.7	96.3	107.6	116.8	122.4	128.0	107.1	47.6	5.8
Sawdust+$(NH_4)_2SO_4$—3.0 pct. N	39.4	57.5	77.1	84.7	93.0	100.9	107.8	112.8	116.8	95.9	42.6	4.2
0.3 PERCENT CALCIUM HYDROXIDE												
Control	2.0	3.9	5.8	7.4	9.4	13.0	16.0	17.8	20.5			8.0
Sawdust	18.5	26.9	37.1	43.7	52.3	68.2	81.1	92.1	103.5	83.0	36.9	8.1
Sawdust+$(NH_4)_2SO_4$—1.5 pct. N	24.9	42.1	67.8	81.3	94.4	106.7	114.7	120.1	125.9	105.4	46.8	7.2
Sawdust+$(NH_4)_2SO_4$—3.0 pct. N	16.5	34.8	62.7	76.7	91.5	105.5	115.8	121.8	128.4	107.9	48.0	6.5
Sawdust+$(NH_4)_2HPO_4$—3.0 pct. N	28.2	47.9	73.9	87.1	99.0	110.0	118.4	124.8	131.6	111.1	49.4	6.6

0.1 PERCENT CALCIUM CARBONATE

Control	9.7	11.9	14.3	15.5	17.2	19.1	21.4	22.9	24.8	----------	----------	6.5
Sawdust	26.8	38.2	48.7	56.6	64.7	79.2	93.0	103.9	117.0	92.7	41.2	6.7
Sawdust+$(NH_4)_2SO_4$—1.5 pct. N	41.2	59.0	80.9	90.6	99.8	113.4	122.4	129.6	135.8	111.0	49.3	5.6
Sawdust+$(NH_4)_2SO_4$—3.0 pct. N	37.1	54.3	77.0	85.6	93.8	102.3	109.4	115.2	119.3	94.5	43.4	4.3

0.4 PERCENT CALCIUM CARBONATE

Control	10.3	12.7	15.6	16.9	18.8	21.4	24.1	26.7	29.3	----------	----------	7.1
Sawdust	27.6	40.7	49.2	56.7	64.5	78.6	92.1	104.0	118.4	89.1	39.6	7.2
Sawdust+$(NH_4)_2SO_4$—1.5 pct. N	41.7	60.2	84.4	95.4	107.6	121.4	131.3	139.1	147.0	117.7	52.3	6.9
Sawdust+$(NH_4)_2SO_4$—3.0 pct. N	37.9	56.8	82.4	94.0	104.5	116.4	125.1	132.5	139.4	110.1	50.4	6.8
Sawdust+$(NH_4)_2HPO_4$—3. pct. N	35.7	54.6	78.3	90.6	103.2	114.6	123.8	130.6	138.0	108.7	49.7	6.6

[1] $(NH_4)_2SO_4$ .... Ammonium sulfate.
$(NH_4)_2HPO_4$ .... Diammonium phosphate.

[2] C evolved from sawdust-soil mixture minus that evolved from controls, which did not receive sawdust.

The addition of nitrogen, with or without lime, increased wood decomposition. During the early stages of the experiment, the CO_2-evolution values were depressed by the larger applications of calcium hydroxide, probably because of fixation of CO_2 as carbonate. Later this CO_2 was released by nitric acid formed biologically.

Calcium carbonate, added at the two rates to soil alone, increased CO_2 evolution by about 35 percent, chiefly because of the neutralization of soil acidity. In the absence of added nitrogen, calcium carbonate increased CO_2 release from sawdust by about 31 percent. Undoubtedly the more favorable pH favored decomposition of wood not only directly but also indirectly by releasing soil nitrogen for use by the wood-decomposing micro-organisms.

These data presented in figures 1 and 2 and tables 1 and 2 show very clearly that sawdust decomposition, as measured by CO_2 evolution, is favored by a neutral soil. The actual amount of wood attacked by micro-organisms may, however, be nearly as great at a pH of 4.0 to 5.0 as at higher pH values since soil acidity favors fungi over bacteria, and the former retain more of their substrate carbon as cell material than do the latter.

COMPARATIVE RATES OF DECOMPOSITION IN SOIL OF WOOD AND BARK PARTICLES OF SEVERAL SPECIES OF TREES, AND THE INFLUENCE OF NITROGEN

Materials and Methods

Branchville sandy loam was used in the experiments on the comparative rates of decomposition in soil of wood and bark sawdust of several species of trees. This soil was leached with water to remove all nitrates, sieved through a 10-mesh sieve, air dried, and stored until used.

The scientific names, sources, and nitrogen and carbon contents of the various woods and barks used are given in table 3. All of these, except black walnut bark, were obtained through the courtesy of various members of the U.S. Forest Service. They were all ground in a Wiley mill to pass a six-mesh sieve and thoroughly air dried prior to use.

The incubation system and fertilizer mixture used were the same as described on page 2. One percent by weight of wood or bark was added to 50 grams of soil in 500-milliliter aeration bottles. Calcium carbonate was added in most tests in the amounts shown in the legends for figures 8 to 35, in the appendix. Nitrogen, expressed as percent of the dry weight of the woods or barks, was added as either ammonium nitrate or urea, as shown in the legends for these figures. Control determinations, consisting of soil without wood or bark but otherwise treated identically, were made and the CO_2-release values subtracted from the corresponding values for the wood-soil mixtures to obtain the values shown in table 4.

TABLE 3.—*Composition of the woods and barks of the tree species used in the decomposition experiments*

Species	Source	Wood		Bark	
		Carbon	Nitrogen	Carbon	Nitrogen
SOFTWOODS		*Percent*	*Percent*	*Percent*	*Percent*
California incense cedar (*Libocedrus decurrens*)	California	51.1	0.097	51.8	0.038
Redcedar (*Juniperus virginiana*)	Virginia	50.8	.139	46.0	.206
Cypress (*Toxidium distichum*)	North Carolina	50.3	.057	47.3	.324
Redwood (*Sequoia sempervirens*)	California	49.9	.060	48.3	.060
Western larch (*Larix occidentalis*)	Montana	48.6	.180	49.9	.161
Eastern hemlock (*Tsuga canadensis*)	Pennsylvania	48.5	.106	51.1	.060
Red fir (*Abies magnifica*)	California	48.2	.227	49.1	.259
White fir (*Abies concolor*)	do	44.8	.045	51.8	.135
Douglas-fir (*Pseudotsuga menziesii*)	Oregon	48.1	.051	52.7	.041
Engelman spruce (*Picea engelmannii*)	Montana	48.5	.118	51.2	.390
White pine (*Pinus strobus*)	Maine	48.3	.087	51.5	.101
Shortleaf pine (*Pinus echinata*)	Maryland	45.0	.130	51.3	.128
Loblolly pine (*Pinus taeda*)	South Carolina	48.7	.068	50.9	.082
Slash pine (*Pinus elliottii*)	Florida	49.2	.050	52.1	.056
Longleaf pine (*Pinus palustris*)	Louisiana	49.9	.038	50.2	.092
Ponderosa pine (*Pinus ponderosa*)	Oregon	45.1	.052	51.8	.048
Western white pine (*Pinus monticola*)	Idaho	48.9	.113	49.5	.171
Lodgepole pine (*Pinus contorta*)	Montana	46.9	.071	49.3	.179
Sugar pine (*Pinus lambertiana*)	California	50.1	.124	51.7	.166
HARDWOODS					
Black oak (*Quercus velutina*)	Illinois	47.3	.070	44.5	.102
White oak (*Quercus alba*)	do	46.9	.104	41.6	.129
Red oak (*Quercus falcata*)	Louisiana	47.4	.099	46.2	.284
Post oak (*Quercus stellata*)	do	47.2	.096	41.8	.270

TABLE 3.—*Composition of the woods and barks of the tree species used in the decomposition experiments*—Continued

Species	Source	Wood		Bark	
		Carbon	Nitrogen	Carbon	Nitrogen
HARDWOODS—continued		*Percent*	*Percent*	*Percent*	*Percent*
Hickory (*Carya* sp.)	Arkansas	46.8	.100	48.1	.413
Red gum (*Liquidambar styraciflua*)	do	46.7	.057	45.1	.177
Yellow-poplar (*Liriodendron tulipifera*)	North Carolina	47.1	.088	47.6	.351
Chestnut (*Castanea dentata*)	do	47.1	.072	47.3	.273
Black walnut (*Juglans nigra*)	South Carolina [1]	47.0	.100	45.1	.177
Averages		48.0	.093	48.7	.174

[1] Bark from Maryland.

Experimental Results

The rates of decomposition (CO_2 release) of the woods and barks of 19 hardwood and 9 softwood species, with and without nitrogen additions, are shown as time curves in figures 8 to 35 in the appendix. In order to facilitate the comparisons, the percentages of carbon released as carbon dioxide from the woods and barks in 60 days were calculated, and are summarized in table 4.

Most of the woods of the softwood species decomposed so slowly that nitrogen additions significantly increased the decomposition of only two of them, shortleaf pine and western white pine, under the experimental conditions (note maximum CO_2 release). Likewise, nitrogen additions did not significantly increase decomposition of any of the softwood barks. On the average, 12.8 percent of the wood carbon was released as CO_2 in 60 days in the absence of added nitrogen, and 12.0 percent in its presence; the corresponding values for bark were 8.8 and 8.2 percent. In a few instances, notably with white pine and loblolly pine woods, the additions of fertilizer nitrogen produced a marked decrease in CO_2 evolution. In these two instances much more nitrogen (2 percent) was added than required by the microorganisms, and in the absence of added $CaCO_3$, the soil pH decreased to 4.6. This depressing effect of excess salt and low pH, mentioned previously, has been observed frequently (*10*) and occurs in experiments with other carbon sources. Such depressing effects were minor in tests involving softwood barks because of their comparatively slow rate of decomposition.

The woods of the 9 hardwood species listed in table 4 (also see figs. 27 to 35) decomposed much more readily than did the woods of the 19 softwood species, with the exception of shortleaf pine. There was much more uniformity among the hardwood species in the amounts of CO_2 evolved in 60 days. In the absence of fertilizer nitrogen, the CO_2 production from these nine woods varied only between 24.9 and 38.1 percent. In the presence of commercial nitrogen, the variations were between 38.5 and 49.1 percent. The decomposition of all nine woods was accelerated by fertilizer nitrogen. The average values for carbon released as CO_2 from the hardwoods in 60 days was 30.3 percent without added nitrogen, and 45.1 percent with nitrogen. The hardwood barks were more resistant to microbial attack than were the woods, but their decomposition was nearly three times as great as that of the softwood barks. The effect of extra nitrogen was minor, the average percentage of carbon released as CO_2 from the hardwood barks being 22.4 and 24.5 percent, without and with nitrogen, respectively.

Decomposition studies with eight of the woods and barks were allowed to continue for periods of 365 to 800 days. These results are summarized in table 5. Since the incubation periods were not the same for all of these wood products, it is not possible to make very many direct comparisons. It is obvious, however, from these data that variations between species are often marked. Some woods, such as redcedar and Ponderosa pine, which decomposed to only a limited extent during the first 60 days, yielded considerable CO_2 later; others, such as sugar pine, were considerably more resistant. White oak, which decomposed comparatively rapidly initially, showed limited CO_2 release later, as would be expected, but the total release was the greatest for any of the woods or barks studied. Delay in CO_2 release from some of the woods, especially great for redcedar, followed by more rapid oxidation later, may indicate initial toxicity of the woods to the microflora. The chief factor controlling decomposition, however, is probably the chemical composition, including the arrangement of the individual molecules. Cellulose, for example, may be readily attacked when in a pure state, but if present in intimate relation to lignin or resinous materials, it may be decomposed slowly, and only as these other wood constituents are broken down.

NITROGEN REQUIREMENTS OF SOIL MICRO-ORGANISMS FOR THE DECOMPOSITION OF VARIOUS KINDS OF WOOD SAWDUSTS

The bacteria, fungi, and actinomycetes that decompose plant materials require considerable nitrogen for the formation of protein and other constituents in their bodies. Since woods and barks contain an average of only 0.1 to 0.2 percent nitrogen (see table 3), the microorganisms must obtain most of their nitrogen supply from other sources, either the soil or nitrogenous materials added to the soil. In the practical use of wood products as mulches or for soil improvement, it is essential to know the maximum quantity of nitrogen that is likely to be immobilized during the period of active decay. If this quantity

TABLE 4.—*Percentage of carbon released as carbon dioxide from woods and barks in 60 days* [1]

Tree species	Nitrogen, where added [2]	Wood carbon released as CO_2		Bark carbon released as CO_2		Final soil reaction	
		No nitrogen added	Nitrogen added	No nitrogen added	Nitrogen added	No nitrogen added	Nitrogen added
SOFTWOODS	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*pH*	*pH*
California incense cedar	2. 00	4. 2	4. 9	6. 5	5. 0	5. 7	4. 6
Redcedar	1. 00	1. 5	3. 9	17. 7	18. 2	7. 5	7. 4
Cypress	1. 25	3. 8	3. 6	5. 9	4. 5	7. 5	7. 5
Redwood	2. 00	3. 8	5. 3	2. 1	2. 1	5. 5	4. 8
Western larch	2. 00	14. 7	11. 7	5. 6	4. 8	5. 9	4. 8
Eastern hemlock	1. 25	7. 5	3. 4	6. 1	4. 2	7. 2	7. 1
Red fir	1. 25	15. 4	8. 0	9. 0	7. 5	7. 1	6. 8
White fir	2. 00	16. 2	11. 8	10. 4	7. 9	5. 7	4. 5
Douglas-fir	1. 00	11. 2	8. 4	10. 6	7. 8	7. 2	6. 8
Engleman spruce	1. 00	19. 0	15. 1	15. 0	16. 1	7. 5	7. 3
White pine	2. 00	16. 4	9. 5	3. 6	3. 0	5. 6	4. 6
Shortleaf pine	1. 00	25. 2	51. 0	4. 4	4. 1	4. 9	4. 5
Loblolly pine	2. 00	17. 0	8. 6	3. 6	3. 5	5. 2	4. 6
Slash pine	1. 25	16. 8	15. 5	7. 3	5. 5	7. 1	6. 6
Longleaf pine	1. 00	16. 4	13. 8	9. 0	9. 3	7. 2	6. 8
Ponderosa pine	1. 00	13. 7	10. 2	9. 6	11. 1	7. 5	7. 4
Western white pine	. 75	16. 2	22. 2	12. 6	13. 8	5. 7	5. 2

Lodgepole pine	1.25	16.3	12.9	23.3	23.2	6.7	6.5
Sugar pine	1.25	7.8	8.0	5.0	3.8	7.0	6.6
Averages	------	12.8	12.0	8.8	8.2	------	------
HARDWOODS							
Black oak	1.50	24.9	46.5	21.3	25.3	5.7	5.1
White oak	1.00	38.1	49.1	27.4	26.4	7.5	7.2
Red oak	1.25	31.9	43.3	22.9	32.2	7.5	7.5
Post oak	1.25	28.1	42.1	23.2	26.2	7.5	7.5
Hickory	1.25	33.7	48.1	11.7	9.6	6.6	6.6
Red gum	1.25	31.3	48.9	21.2	20.0	6.7	6.7
Yellow-poplar	1.25	30.6	44.3	37.5	42.0	7.5	7.5
Chestnut	1.25	26.6	38.5	23.1	27.6	6.6	6.6
Black walnut	1.25	27.1	44.7	13.7	11.4	6.6	6.6
Averages	------	30.3	45.1	22.4	24.5	------	------
Averages, all species	------	18.5	22.6	13.2	13.4	------	------

[1] Comparative studies showed a release of 54.6 percent of the carbon of wheat straw as CO_2 in 60 days.
[2] Percentage of weight of added wood.

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TABLE 5.—*Percentage of wood and bark carbon evolved as CO_2 in longtime experiments*

Tree species	Incubation period	CO_2 evolved					
		From wood			From bark		
		Total	During 1st 60 days	After 60 days	Total	During 1st 60 days	After 60 days
	Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Slash pine	365	28. 3	16. 8	11. 5	12. 2	7. 3	4. 9
Sugar pine	365	20. 9	8. 0	12. 9	8. 4	5. 0	3. 4
Douglas-fir	580	37. 9	11. 2	26. 7	40. 9	10. 6	30. 3
Longleaf pine	580	44. 7	16. 4	28. 3	21. 3	9. 3	12. 0
White oak	580	65. 3	49. 1	16. 2	54. 7	27. 4	27. 3
Red cedar	800	34. 6	3. 9	30. 7	50. 2	18. 2	32. 0
Engelman spruce	800	47. 3	19. 0	28. 3	34. 7	16. 1	18. 6
Ponderosa pine	800	57. 7	13. 7	44. 0	29. 3	11. 1	18. 2

of nitrogen is not supplied, not only is the rate of wood decay likely to be lower than with adequate nitrogen, but any crop growing on the soil may suffer from nitrogen deficiency as the micro-organisms compete with it for the available nitrogen supply.

The quantity of nitrogen that is immobilized when a plant material, such as straw, is added to a soil varies with time. In the experiments of Allison and Klein (*5*), for example, the quantity of nitrogen immobilized by straw during periods of 5, 10, 20, and 40 days was approximately 0.75, 1.25, 1.70, and 1.35, respectively, expressed as percentage of the dry weight of the straw. Some of the nitrogen that was immobilized initially was released (mineralized) later. This initial increase in immobilization to a maximum, followed by a slow decrease later, is characteristic for all readily decomposable plant materials. In practice it is the maximum observed immobilization value (1.7 percent in the case of straw) that is of most interest and, in agreement with common usage, it is this maximum value that is meant here when the term nitrogen requirement is used.

The experiments reported here were designed to determine the amount of nitrogen immobilized when a number of softwood and hardwood species were allowed to decompose for different periods of time. Such data not only supply information on the rates of nitrogen immobilization and of wood decay, but also show maximum immobilization, or nitrogen requirement.

Materials and Methods

All woods described in table 3 were used in these studies. Wheat straw, containing 0.4 percent nitrogen and 42.6 percent carbon, was included for comparative purposes.

Leached Branchville sandy loam was again used. The fertilizer mixture, used in all tests, was that described on page 2. In addition, 200 milligrams of $CaCO_3$ per 50 grams of soil were added to maintain the pH at near neutrality.

The soils were incubated in 500-milliliter Erlenmeyer flasks fitted with one-hole rubber stoppers and kept at 30° C. The use of one-hole stoppers assures good aeration and a minimum loss of moisture during incubation. Moisture was maintained at 65 percent of water-holding capacity. The treatments for each wood were (*a*) 50 grams of soil plus 1 percent wood sawdust that passed through a 6-mesh sieve, and sufficient nitrogen as sodium nitrate to bring the nitrogen content of the wood up to 2 percent (more than adequate for the needs of the micro-organisms); and (*b*) the same quantity of total nitrogen as in (*a*), but without wood. All treatments were repeated 10 times to allow for analysis in duplicate after five incubation periods.

Analyses for soil nitrate content were made at intervals by the phenoldisulfonic acid method. The quantity of nitrogen immobilized by the micro-organisms was determined by substracting the nitrate values for the soils containing the woods from those without woods ((*b*) − (*a*), above).

Experimental Results

The quantities of nitrogen immobilized by the 28 wood species during decomposition periods of 10 to 160 days are shown in table 6. The maximum values (nitrogen requirements) range between 0.3 and 1.4

TABLE 6.—*Nitrogen immobilized by micro-organisms in the decomposition of various wood species in soil*

Tree species	Nitrogen immobilized [1] after—				
	10 days	20 days	40 days	80 days	160 days
SOFTWOODS	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
California incense cedar	0.17	0.25	0.52	0.69	0.52
Redcedar	.17	.22	.17	.28	.41
Cypress	.13	.08	.17	.25	.37
Redwood	.13	.22	.21	.31	.34
Western larch	.20	.21	.44	.64	.79
Eastern hemlock	.08	.08	.20	.35	.42
Red fir	.22	.14	.36	.54	.83
White fir	.04	.00	.25	.35	.54
Douglas-fir	.07	.21	.07	.14	.30
Engelmann spruce	.15	.06	.48	.69	.74
White pine	.08	.05	.29	.48	.41
Shortleaf pine	.78	1.00	1.27	1.30	1.13
Loblolly pine	.01	.15	.31	.63	.60
Slash pine	.04	.02	.17	.46	.64
Longleaf pine	.01	.00	.15	.30	.49
Ponderosa pine	.05	.07	.19	.44	.42
Western white pine	.11	.08	.35	.61	.89
Lodgepole pine	.07	.01	.29	.61	.80
Sugar pine	.13	.15	.33	.43	.54
Averages	.14	.16	.33	.50	.59
HARDWOODS					
Black oak	0.86	1.17	1.21	1.20	1.05
White oak	.62	.96	1.19	1.15	1.09
Red oak	.93	1.20	1.40	1.23	1.16
Post oak	.77	1.07	1.27	1.25	1.20
Hickory	.78	1.00	1.12	1.17	1.07
Red gum	.90	1.28	1.24	1.18	1.04
Yellow-poplar	.98	1.19	1.13	1.15	1.05
Chestnut	.38	.88	1.14	1.07	1.13
Black walnut	.80	1.18	1.20	1.15	1.07
Averages	.78	1.10	1.21	1.17	1.10
Averages, all woods	.35	.46	.61	.72	.75
Wheat straw	1.25	1.68	1.35	1.14	-------

[1] In percentage of dry weight of wood.

percent of the dry weights of the woods, with an average value of 0.8 percent. The corresponding value for wheat straw is 1.7 percent. The nitrogen requirements averaged 0.6 percent for the softwoods and 1.2 percent for the hardwoods. All of the nine hardwoods had nitrogen requirements greater than 1.0 percent, but only one softwood, shortleaf pine, had a value this high.

In figure 3 the maximum quantity of nitrogen immobilized by each of the woods is plotted against the corresponding CO_2-evolution values for the 60-day incubation period given in table 4. It will be observed that these values tend to fall into two groups. All of the values for the hardwoods are at the top of the scale, and all of the softwoods, except shortleaf pine, fall near the lower end of the scale. The correlation coefficient is 0.93. The close agreement between nitrogen immobilized and CO_2 released is in agreement with the results obtained with wheat straw and sucrose, discussed elsewhere (*5*). It should be pointed out that the CO_2-release values for the various woods are not strictly comparable because the experiments were not all conducted at the same soil pH value. The effect of pH was, however, a

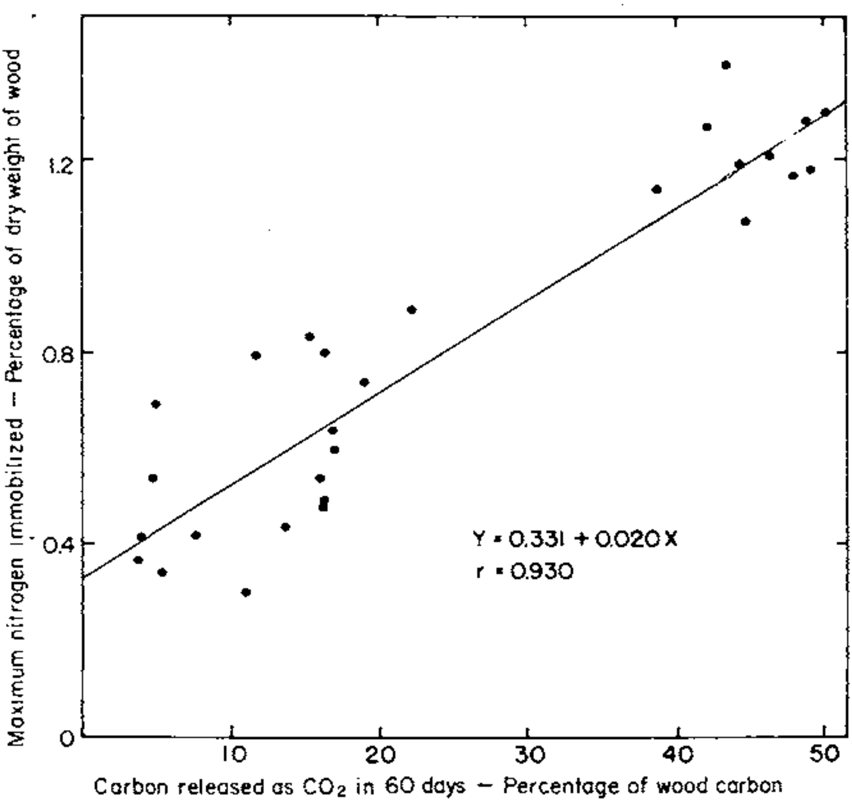

FIGURE 3.—The relationship between nitrogen requirements for the decomposition of various woods and CO_2 evolution during a 60-day incubation period.

comparatively minor one. Since such a small percentage of the carbon of many of the softwoods was oxidized, it is not surprising that so little nitrogen was utilized. These values in some instances even seem high, possibly suggesting that some of the woods may have slightly retarded the mineralization of the soil organic nitrogen.

Maximum nitrogen immobilization values for the 10 woods that decomposed most rapidly were usually observed in about 40 days. During the following 120 days these values decreased about 9 percent, which is less than the decrease observed (*5*) with straw and sucrose for much shorter periods. The softwoods, other than shortleaf pine, decomposed so slowly that the maximum nitrogen immobilization values were usually not observed until decomposition had proceeded 80 to 160 days.

The wide differences in the rates of decay and in the nitrogen requirements of the various woods are emphasized by these data. These differences are undoubtedly due primarily to the variations in chemical composition of the woods and to the relative ease with which the micro-organisms can attack the individual constituents. If the effects of leaching (always a factor under practical conditions) are discounted, none of the woods would require more than about 25 pounds of nitrogen per ton of dry sawdust for decomposition. Most softwoods and barks would need only half this amount or less.

EFFECT OF SEVERAL WOODS AND BARKS ON GERMINATION AND EARLY GROWTH OF GARDEN PEAS

The addition of sawdust, only, to soils in appreciable amounts commonly decreases crop growth for a period ranging from a few days to a year or more, depending largely upon the kind and amount of wood product added. This decrease is usually due to the biological immobilization of the soil nitrogen supply, as discussed on page 17. Occasionally the availability of phosphorus, and possibly other elements, may also be affected. Direct toxic effects on plant growth, caused by chemical compounds in the woods and not corrected for by lime and fertilizer, are usually not encountered to any significant extent (*1, 9, 10, 17, 20, 21*).

Some evidence has been obtained, however, which shows that a few woods or barks may be harmful to certain plants. Resins, turpentine, and tannin in large amounts were found to be toxic by Koch (*15*) and by Koch and Gelsner (*16*), but later workers (*10*) have reported that these materials are decomposed fairly rapidly in soil. Brown (*11*) reported that alfalfa and tomato seedlings were injured by green walnut bark, and that nitrate additions did not fully correct the injury; the roots were stunted, shriveled, and discolored by the walnut but not by apple or sumac. Hughes (*14*) states that toxic sulfides are formed when certain kinds of hardwood sawdusts undergo decomposition.

Newton (*18*) reported a marked depression of the growth of young beans, garden peas, and sweetpeas when the seeds were planted in pure cedar sawdust, but there was no significant depression when hemlock, fir, or balsam was used. The germination of radish seeds and their early growth were decreased when they were planted in the four sawdusts mixed with soil at the rate of 20 to 30 percent by volume. There is no doubt about the toxicity of cedar, but the effects observed with the other woods may have been largely the result of immobilization of available nitrogen.

Gibbs and Batchelor (*12*) observed that cedar sawdust exerted a marked toxic effect, and red fir a slightly harmful effect, on nitrogen fixation by Azotobacter growing in mannite nutrient solutions. There was no such effect where ash, yellow pine, white fir, maple, larch, and white pine sawdusts were added.

The effects of 28 kinds of woods and barks on the germination and early growth of garden peas are reported in this section.

Materials and Methods

Elsinboro sandy loam topsoil, obtained locally, was used in all experiments. This soil had been cropped for a number of years and limed occasionally. It was sieved through a six-inch sieve, air dried, and stored for short periods. Sufficient additional calcium carbonate was added to adjust the pH to approximately 6.5. The experiments were conducted in gallon cans containing 6 pounds of soil.

The rates of addition of the finely ground woods and barks (listed in table 3) ranged between 1 and 8 percent by weight, which corresponds to approximately 6 to 48 percent by volume of the woods, and somewhat more than this for the barks. Not all the rates—1, 2, 4, and 8 percent by weight—were applied for each tree species used. All cans of soil that received either 1 or 2 percent of the wood products also received 3,000 pounds per acre (2,000,000 pounds of soil) of a 5-10-10 fertilizer; where 4 or 8 percent of these materials was added, the fertilizer addition was 3,000 pounds per acre of a 10-10-10 fertilizer. All nitrogen was supplied as urea. The wood products, lime, and fertilizer were thoroughly mixed with the soil. Thirty seeds of Alaska garden peas, inoculated with an effective strain of *Rhizobium*, were planted in each can and enough water was added to bring the soil moisture level to approximately 60 percent of field capacity.

The experiments were conducted in triplicate in an air-conditioned light chamber, using artificial illumination. The room temperature was held at 70 to 75° F., but directly under the bank of lights the temperature was usually about 80°. The moisture lost by evapotranspiration was replaced once or twice daily. A total of 8 experiments, each consisting of 100 to 110 cans, was conducted. Direct comparisons between the woods and barks of a given species were made in all tests. White oak, black oak, and loblolly pine were studied in two experiments; all other woods were used in four to seven separate experiments. A second crop of peas was seeded immediately following the harvesting of the first crop in all but two of the experiments. Where these additional plantings were made, a further addition of 150 pounds of urea nitrogen per acre was made to all cans that had initially received 2 percent or more of the wood products.

Germination counts were made after about a week and plant growth observations were made frequently. The peas were harvested when they were in full bloom and 8 to 13 inches in height. The growth period from the time of seeding ranged between 19 and 28 days, depending chiefly upon the length of day used. The dry weights of the aboveground portions of the pea plants were recorded.

Experimental Results

The experimental data obtained, which are rather extensive, can best be reported statistically. To do this, the germination counts and crop weights for the first and second crops were analyzed by the usual analysis of variance method, and all significant depressions below the values for the control soil, containing complete fertilizer but no wood products, were noted. Occasionally a sawdust showed a decrease in germination or growth at the 5-percent level of significance, but a later experiment at a higher level of sawdust showed no significant depression. The wood in such cases was considered nontoxic.

Figures 4 to 7 show the growth of garden peas in one experiment, where 12 kinds of woods and barks were added to soil at the 2-percent rate. The pictures were taken 22 days after seeding which was 3 days prior to harvesting.

The growth of peas, as shown in figure 4, was definitely reduced by California incense cedar wood but only slightly by the bark of this species, and by the wood and bark of redcedar. Ponderosa pine wood and bark, and white pine wood produced no visible effects on the peas, but white pine bark was markedly toxic. (See fig. 5.) The peas in figure 6 showed essentially normal growth in the presence of both the woods and barks of loblolly and longleaf pines. Figure 7 shows that there was no visibly harmful effect on peas produced by red gum wood or bark, or by yellow-poplar wood, but that growth was appreciably retarded by the yellow-poplar bark.

FIGURE 4.—Growth of garden peas in soil containing 2 percent of California incense cedar and redcedar woods and barks. No. 3=control; 90=California incense cedar wood; 95=California incense cedar bark; 104=redcedar wood; and 105=redcedar bark.

FIGURE 5.—Growth of garden peas in soil containing 2 percent of Ponderosa pine and white pine woods and barks. No. 3=control; 98=Ponderosa pine wood; 101=Ponderosa pine bark; 86=white pine wood; and 110=white pine bark.

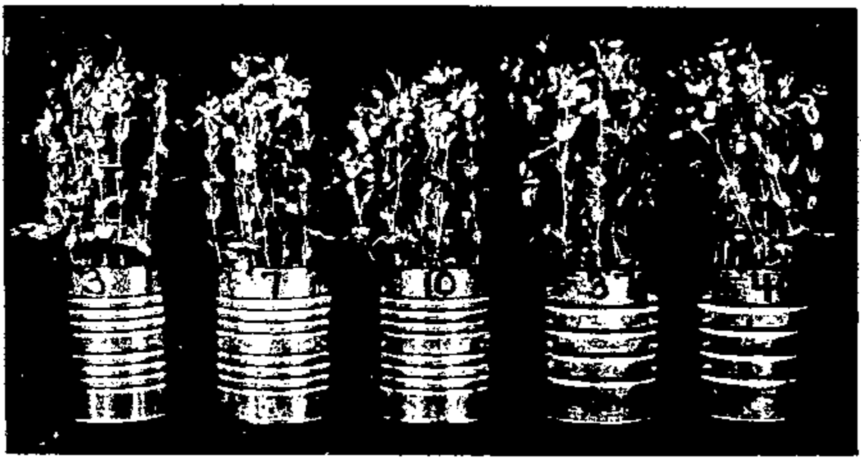

FIGURE 6.—Growth of garden peas in soil containing 2 percent of loblolly pine and longleaf pine woods and barks. No. 3=control; 7=loblolly pine wood; 10=loblolly pine bark; 37=longleaf pine woods; and 40=longleaf pine bark.

Table 7 shows that, at the rates used, neither the woods nor barks of 22 of the 28 tree species studied showed significant toxicity to peas. Of the remaining woods or barks, two produced severe toxicity and four slight growth inhibition. California incense cedar wood had a toxic effect on both germination and growth, even at the 1- and 2-percent rates. The bark did not affect germination at the 2- and 4-percent rates, but slightly retarded growth. White pine wood was not toxic, but the bark was somewhat injurious to germination, and very

FIGURE 7.—Growth of garden peas in soil containing 2 percent of red gum and yellow-poplar woods and barks. No. 3=control; 49=red gum wood; 51=red gum bark; 80=yellow-poplar wood; and 81=yellow-poplar bark.

injurious to pea seedlings at both the 1- and 2-percent rates. Redcedar wood and bark had no effect on germination, but were slightly inhibitory to pea seedlings at the 2-percent rate. Loblolly pine and Ponderosa pine woods and barks did not affect germination, but the woods slightly reduced the growth of seedlings. Yellow-poplar wood was without effect, but the bark showed some harmful effect on seedlings at the 2- and 4-percent rates.

The finding that cedar is toxic is in agreement with the reported observations of others (*12, 13, 18*), but, so far as is known, the severe toxicity of white pine bark has not been demonstrated previously. Black walnut bark, previously reported (*11*) as toxic to alfalfa and tomato seedlings, was not toxic in the present studies. The difference is probably due to the nature of the bark samples: Brown (*11*) used green root bark, whereas the author used weathered bark from a large tree. Such variations are to be expected for different samples of barks, and possibly also of woods.

The growth of a second crop of peas, following an earlier crop where toxicity had been observed, commonly showed less severe toxicity symptoms, but the earlier toxicity seldom disappeared completely. This was particularly true for California incense cedar and white pine bark. Biological destruction of the toxic constituents in these woods, at least, seems to proceed slowly. The nature of the toxic substances was not determined.

The pea plants growing in the various sawdust-soil mixtures showed no visible signs of nitrogen deficiency or harmful excess. Evidently the quantities of urea added were entirely adequate to meet the needs of the micro-organisms and crop during the short growth periods. Any possible nitrogen deficiency could have been met by fixation of atmospheric nitrogen, since all the peas were inoculated and were fairly well nodulated in most treatments, even where abundant available nitrogen was present.

The studies reported in table 7 show that most woods and barks are not appreciably toxic to peas and may be used safely as mulches or mixed with soil if adequate nutrients and lime, if needed, are added. The few wood products that are toxic should be avoided, or sufficient time for considerable biological decomposition should be allowed before crops, especially seedlings, are exposed to them.

DISCUSSION

These experiments show that there are wide differences in the rates of decomposition of the woods and barks of the various species of trees. These variations are due, primarily, to the chemical composition of these wood products, including the structure of and interrelationships between the different chemical constituents in the wood fibers. In general, the percentage of readily available energy sources in the woods and barks is much lower than that in common agricultural crop residues. There is some evidence in the literature that slow decomposition of a few woods may be due in part to the presence of substances that are inhibitory to biological activity. It is not believed that such inhibitory substances are a factor of much importance in longtime decomposition studies.

The nitrogen requirements of the micro-organisms that decomposed the 28 woods (listed in table 6) ranged between 0.3 percent of the dry weight of the wood for Douglas-fir and 1.4 percent for red oak. The corresponding value for wheat straw was 1.7 percent. These nitrogen-requirement values for the various woods serve as a reasonably quantitative estimate of the readiness with which the woods are attacked biologically. They agree closely with the corresponding CO_2-evolution values. Although nitrogen-requirement values for the barks were not obtained, the CO_2-evolution data for these barks show that most of them decomposed more slowly than the woods, and hence would have lower nitrogen requirements. The nitrogen that is thus immobilized by the sawdusts is, of course, slowly released later.

The toxicity studies showed that only California incense cedar wood and white pine bark were severely harmful to garden peas grown in the presence of adequate amounts of nutrients and lime, although some of the other wood products were slightly inhibitory to seedling growth. If strongly inhibitory products are to be used in large quantities as a mulch, or mixed with soil, it is obvious that a crop should not be seeded immediately. If these products are allowed to decompose in or on the soil, or undergo considerable weathering, most of their toxicity should disappear. It should be emphasized, however, that most wood products do not contain a concentration of toxic compounds high enough to appreciably affect their use in agriculture.

In connection with toxicity, it is well to call attention to the observation of Boilen and Glennie (*9*). They state that sometimes a pile of new sawdust may undergo anaerobic fermentation and become

TABLE 7.—*The toxicity*[1] *of woods and barks to garden peas grown in Elsinboro sandy loam*

Tree species	Rate of application, percent															
	Wood				Bark				Wood				Bark			
	1	2	4	8	1	2	4	8	1	2	4	8	1	2	4	8
	Effect on germination								Effect on early growth							
SOFTWOODS																
California incense cedar	+	++	+++	-----	0	0	0	-----	++	++	+++	-----	0	+	+	-----
Redcedar	0	0	-----	-----	0	0	-----	-----	0	+	-----	-----	0	+	-----	-----
Cypress	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Redwood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Western larch	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
Eastern hemlock	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
Red fir	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
White fir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Douglas-fir	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
Engelman spruce	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
White pine	0	0	0	-----	+	+	-----	-----	0	0	0	-----	++	+++	-----	-----
Shortleaf pine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loblolly pine	0	0	-----	-----	0	0	-----	-----	0	+	-----	-----	0	0	-----	-----
Slash pine	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
Longleaf pine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ponderosa pine	0	0	-----	-----	0	0	-----	-----	0	+	-----	-----	0	0	-----	-----
Western white pine	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
Lodgepole pine	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----	0	0	-----	-----
Sugar pine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

HARDWOODS																
Black oak	0	0	------	------	0	0	------	------	0	0	------	------	0	0	------	------
White oak	0	0	------	------	0	0	------	------	0	0	------	------	0	0	------	------
Red oak	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post oak	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red gum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-poplar	0	0	0	------	0	0	0	------	0	0	0	------	0	+	+	------
Chestnut	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black walnut	0	0	------	------	0	0	------	------	0	0	------	------	0	0	------	------

[1] Toxicity: 0=none; +=slight: toxicity at the 5-percent level of significance; ++=moderate: toxicity at the 1-percent level of significance; +++=severe: toxicity at the 0.01-percent level of significance.

supersaturated with volatile organic acids and other fermentation products that are very injurious to plants. Such a sawdust may become brown or black, have a sharp, acid odor, and give off irritating fumes. Extensive weathering and addition of lime usually remove or counteract the toxicity. Fortunately, such sawdusts are seldom encountered.

The studies reported here show that, with few exceptions, the woods and barks of various tree species can be utilized satisfactorily in agriculture as mulches and as soil humus sources. They are of especial value in the improvement of the physical properties of heavy clay soils and may help materially in the maintenance of the organic matter content of all soils. It is necessary, however, to be certain that adequate fertilizer, especially nitrogen, is applied with the sawdusts to counteract the effects of the wood products. The quantity of additional nitrogen needed, shown in table 6, varies widely with species. If the effects of leaching are disregarded, none of the woods or barks would require more than about 25 pounds of nitrogen per ton of dry sawdust for decomposition. Most softwoods and barks would need only half this amount or less. More of this nitrogen is needed during the 1 or 2 months of initial, very active decomposition. Under conditions of heavy rainfall, nitrogen beyond these amounts should be supplied, preferably in small increments as decomposition proceeds, and as the crop needs it. The addition of large amounts of nitrogen fertilizers at times when there is no crop present is seldom advisable.

Where soils are very acid, additions of lime should be made to neutralize the natural soil acidity and to counteract any acidity that may develop following the addition of the supplemental nitrogen sources. The undecomposed wood products, themselves, seldom have any appreciable effect on soil reaction.

SUMMARY

Laboratory and vegetation studies with finely ground woods and barks of 28 species of trees are reported. The following softwoods were used: California incense cedar, redcedar, cypress, redwood, western larch, eastern hemlock, red fir, white fir, Douglas-fir, Engelman spruce, white pine, shortleaf pine, loblolly pine, slash pine, longleaf pine, Ponderosa pine, western white pine, lodgepole pine, and sugar pine. The hardwood species used were: black oak, white oak, red oak, post oak, hickory, red gum, yellow-poplar, chestnut, and black walnut. The following results were obtained with these products used in mixture with loam soils.

1. Shortleaf pine wood particles that barely passed through a 6-mesh sieve decomposed about as rapidly as did those of finer grind. Under the experimental conditions, where the air above the soil was always saturated with water, wood particles placed on the soil surface released CO_2 at about the same rate as when mixed with the soil.

2. The decomposition of a readily decomposable sawdust (such as shortleaf pine) proceeded slightly more rapidly if the soil reaction was maintained near neutrality than at a pH of 4 to 5.

3. Nitrogen supplied as ammonium or nitrate salts, or as urea, gave equally good results in decomposition experiments with the more readily decomposable woods if the pH was kept above 6.

4. The softwoods, other than shortleaf pine and western white pine, decomposed so slowly when present in soil (Branchville sandy loam) at the 1-percent rate that no nitrogen other than that supplied by the soil was needed for a maximum rate of CO_2 release. This would not always be true for other soils and other rates of addition of wood. On the average, 12.8 percent of the wood carbon was released as CO_2 in 60 days in the absence of added nitrogen, and 12.0 percent in its presence; the corresponding values for bark were 8.8 and 8.2 percent.

5. The hardwoods decomposed much more readily than did most of the softwoods. The CO_2 release from the nine hardwoods in 60 days averaged 30.3 percent without fertilizer nitrogen and 45.1 percent with additional nitrogen; the corresponding values for the barks were 22.4 and 24.5 percent.

6. The CO_2 release from six woods that were allowed to decompose for 580 to 800 days ranged between 34.6 and 65.3 percent for the woods and between 21.3 and 54.7 percent for the barks. There was considerable variation between species but, on the average, the CO_2 release from the barks in these longtime experiments was about 80 percent of that of the woods.

7. The maximum quantities of nitrogen immobilized (nitrogen requirement) by the micro-organisms that decomposed the woods ranged between 0.3 and 1.4 percent of the dry weight of the woods; the corresponding value for wheat straw was 1.7 percent. The nitrogen requirements averaged 0.61 percent for 19 softwoods and 1.22 percent for 9 hardwoods. The nitrogen requirements of the woods correlated very closely with the carbon dioxide evolution values for the first 60 days.

8. Garden peas grown in soil-sawdust mixtures with adequate nutrients present showed no significant toxic effects from the woods and barks of 22 of the 28 species tested. The wood of California incense cedar was very toxic to germination and growth, even at the 1- and 2-percent rates. The bark slightly retarded growth at the 2- and 4-percent rates. White pine bark was somewhat harmful to germination and very injurious to pea seedlings at the 1- and 2-percent rates. Redcedar wood and bark had no effect on germination, but were slightly inhibitory to pea seedlings at the 2-percent rate. Yellow-poplar bark and woods of Ponderosa pine and loblolly pine slightly injured growth. In all these experiments the harmful effects were less in evidence on a second crop of peas than on the first, but usually had not entirely disappeared.

9. Woods and barks, with few exceptions, can be used satisfactorily in agriculture as mulches, and for soil humus maintenance, if adequate amounts of nutrients, especially nitrogen and sometimes lime, are supplied. Most woods behave similarly to common carbonaceous crop residues, except that they decompose more slowly because they contain less available carbohydrate and more lignin.

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APPENDIX

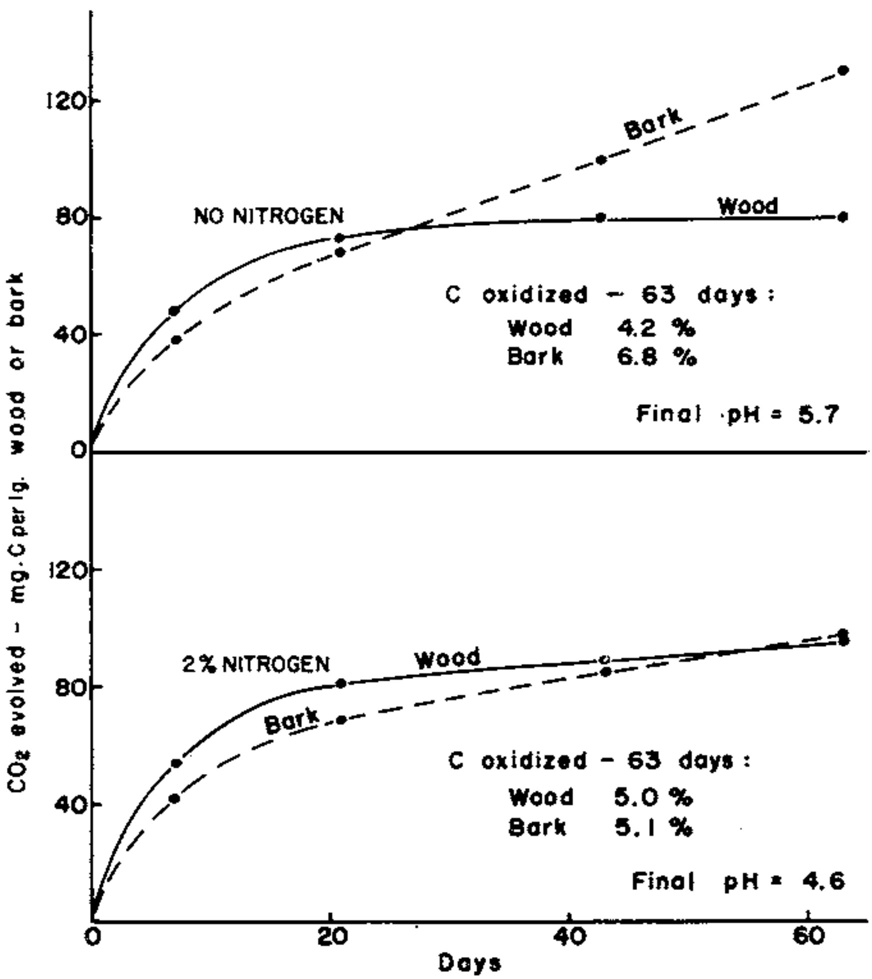

FIGURE 8.—Decomposition of California incense cedar wood and bark in soil receiving 0.1 percent $CaCO_3$ with and without nitrogen as ammonium nitrate.

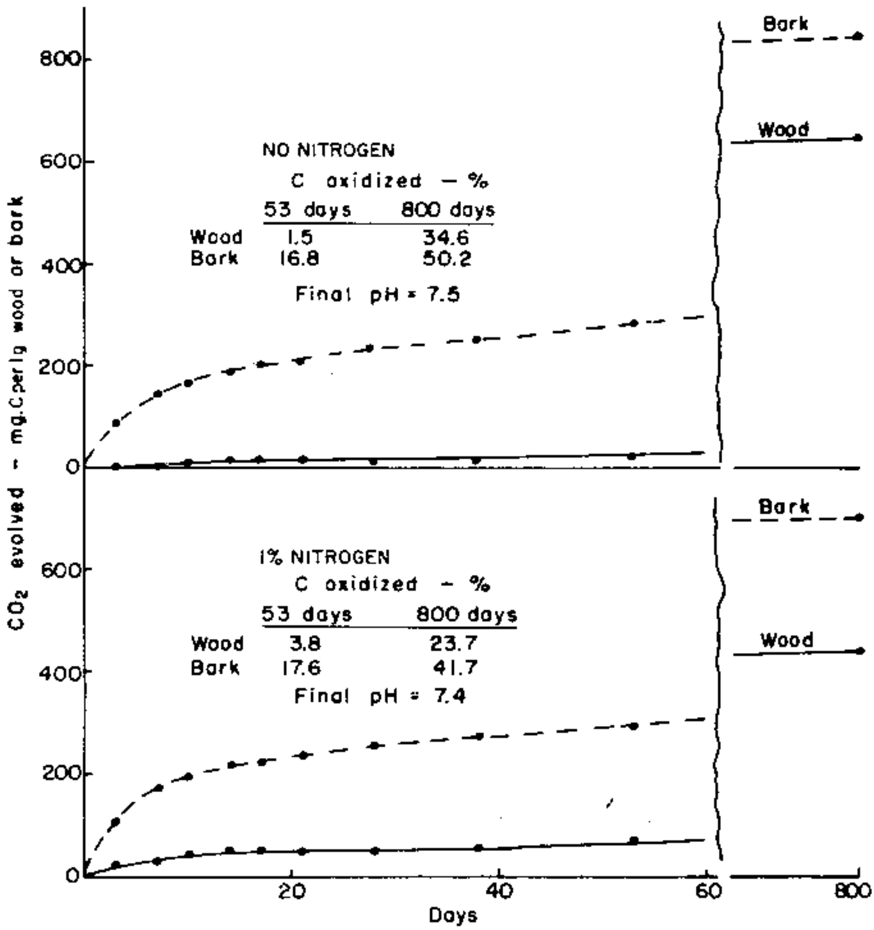

FIGURE 9.—Decomposition of redcedar wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

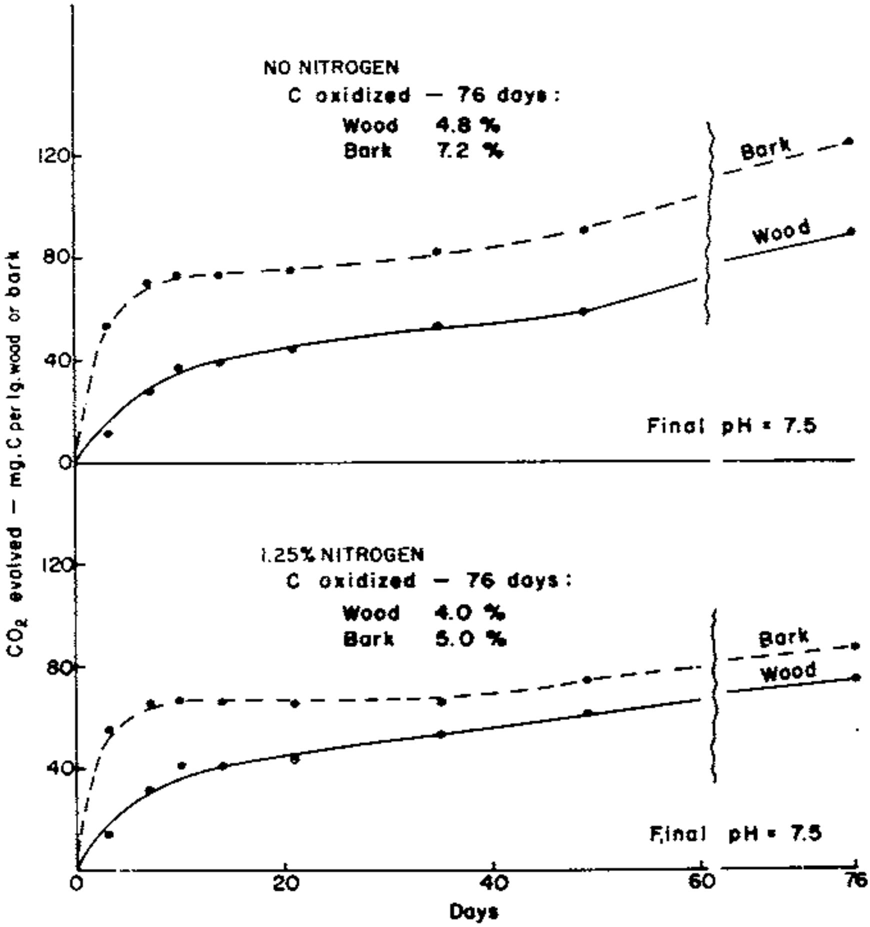

FIGURE 10.—Decomposition of cypress wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

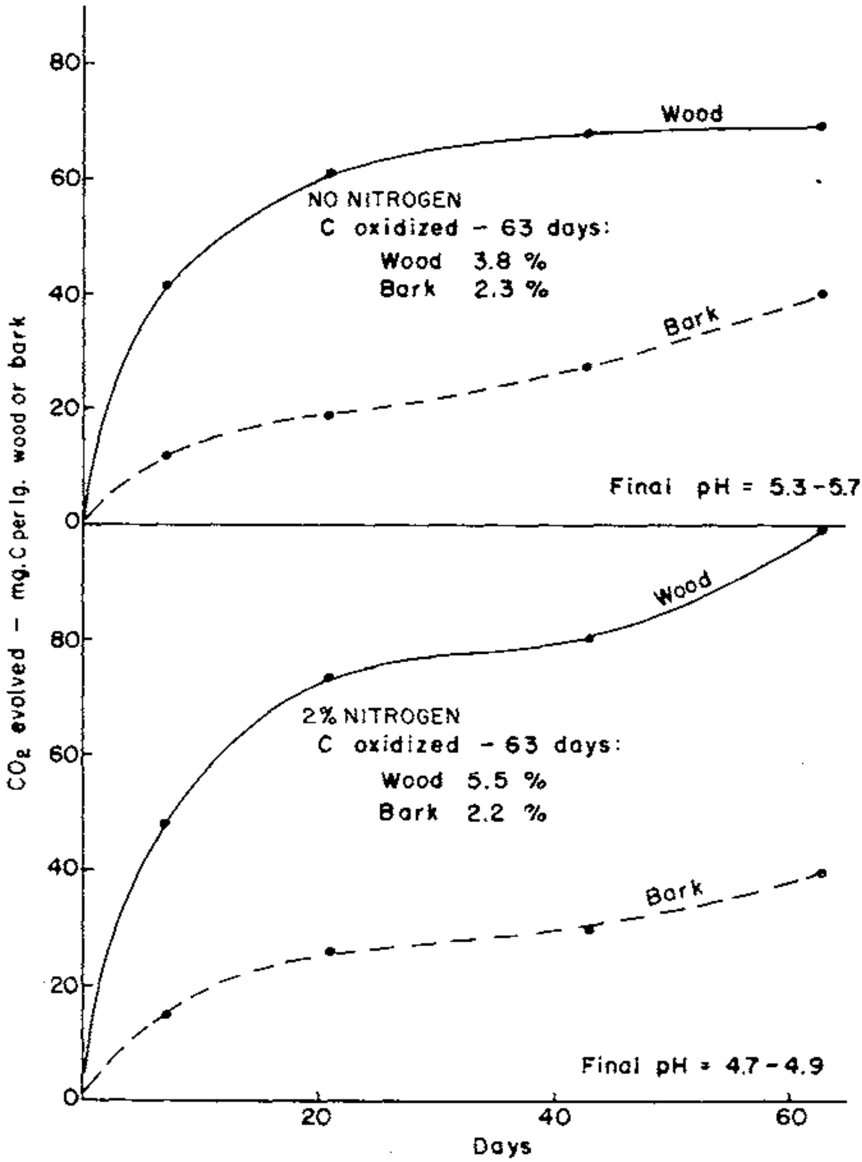

FIGURE 11.—Decomposition of redwood and bark in soil receiving 0.1 percent $CaCO_3$ with and without nitrogen as ammonium nitrate.

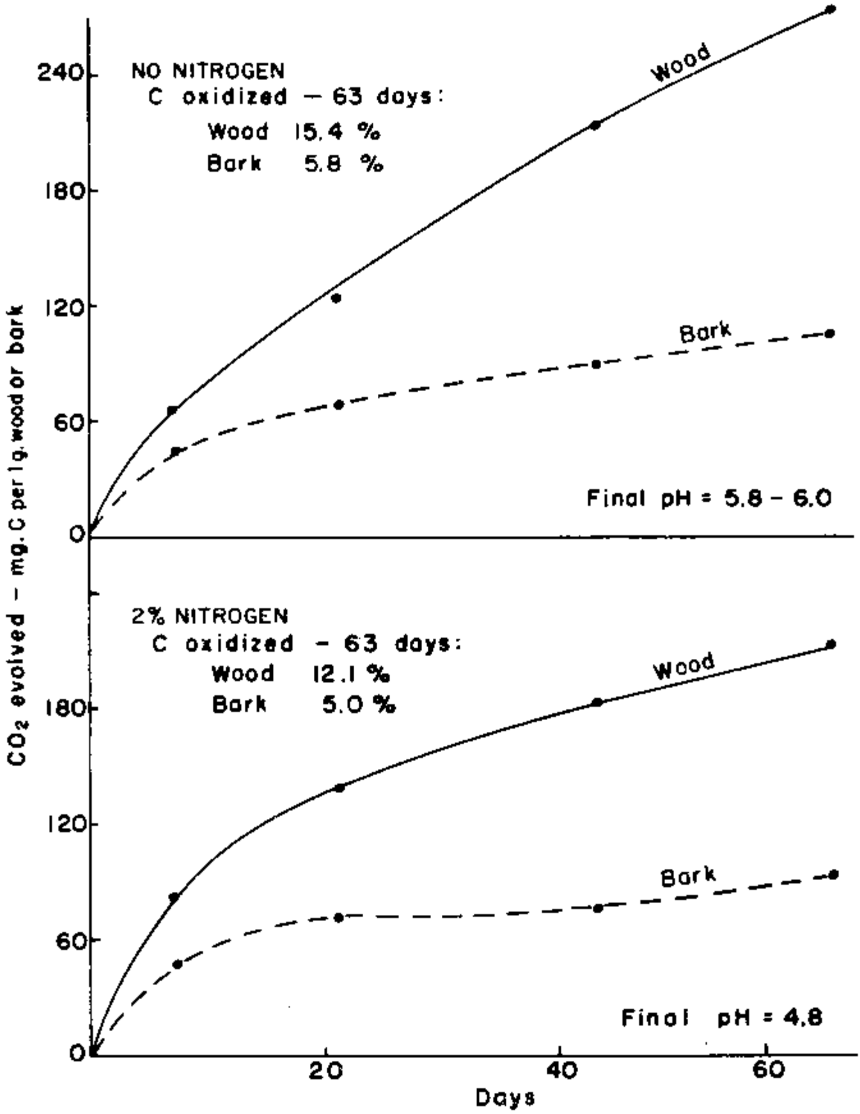

FIGURE 12.—Decomposition of western larch wood and bark in soil receiving 0.1 percent $CaCO_3$ with and without nitrogen as ammonium nitrate.

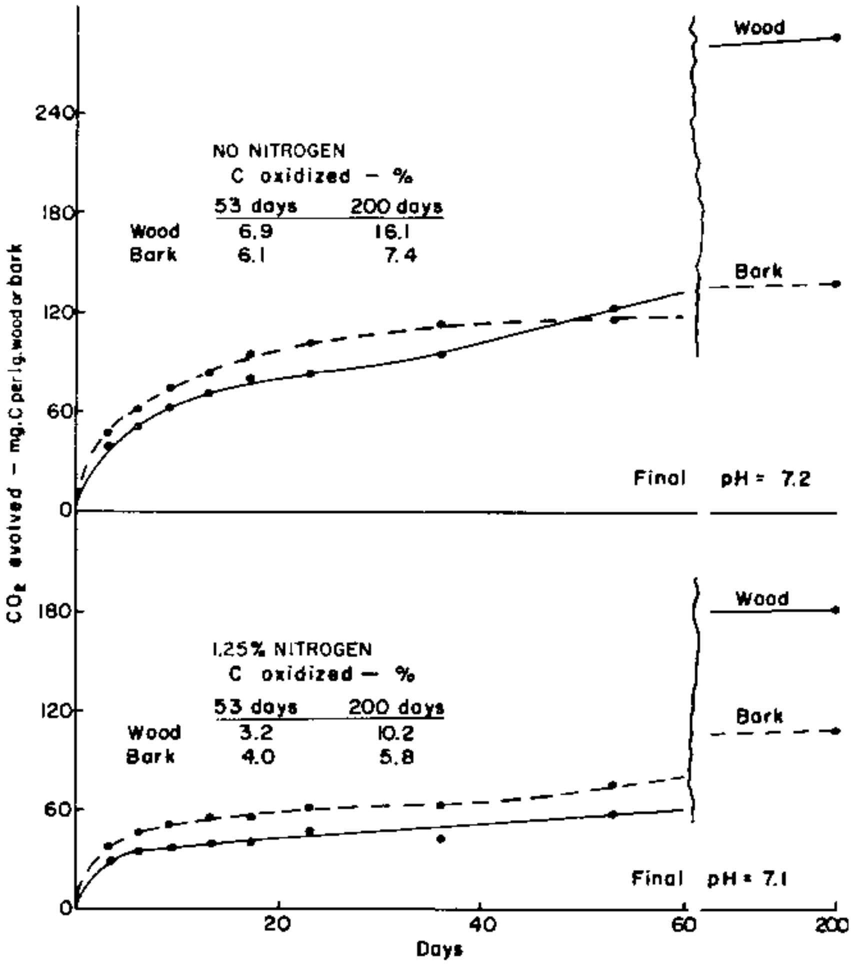

FIGURE 13.—Decomposition of eastern hemlock wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

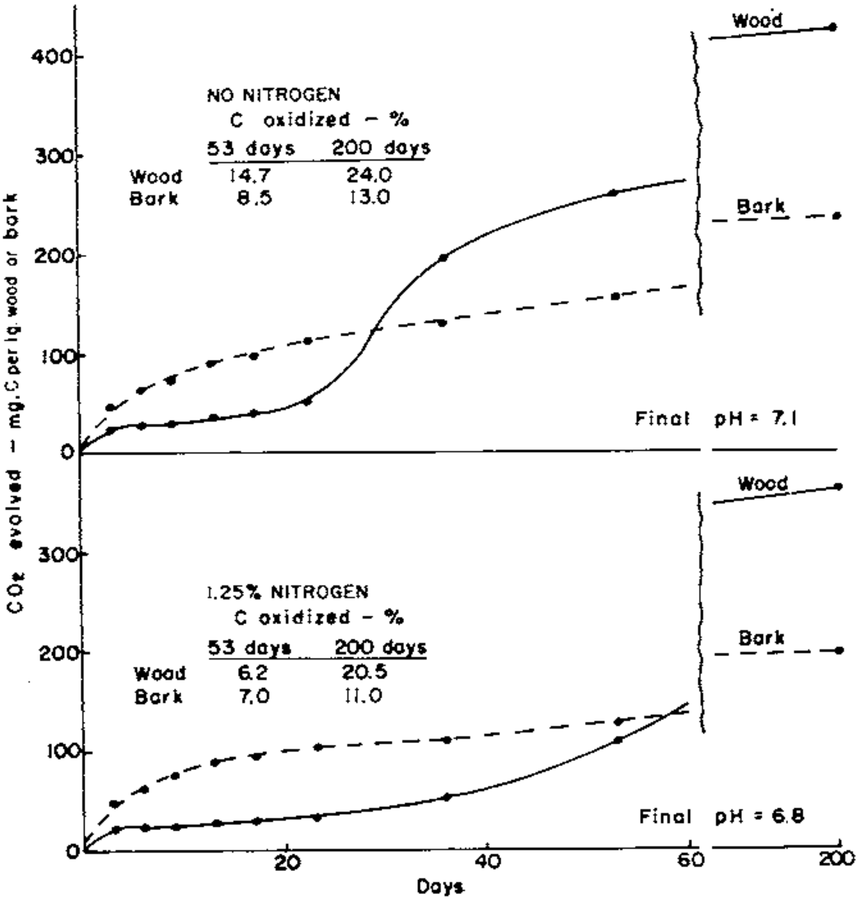

FIGURE 14.—Decomposition of red fir wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

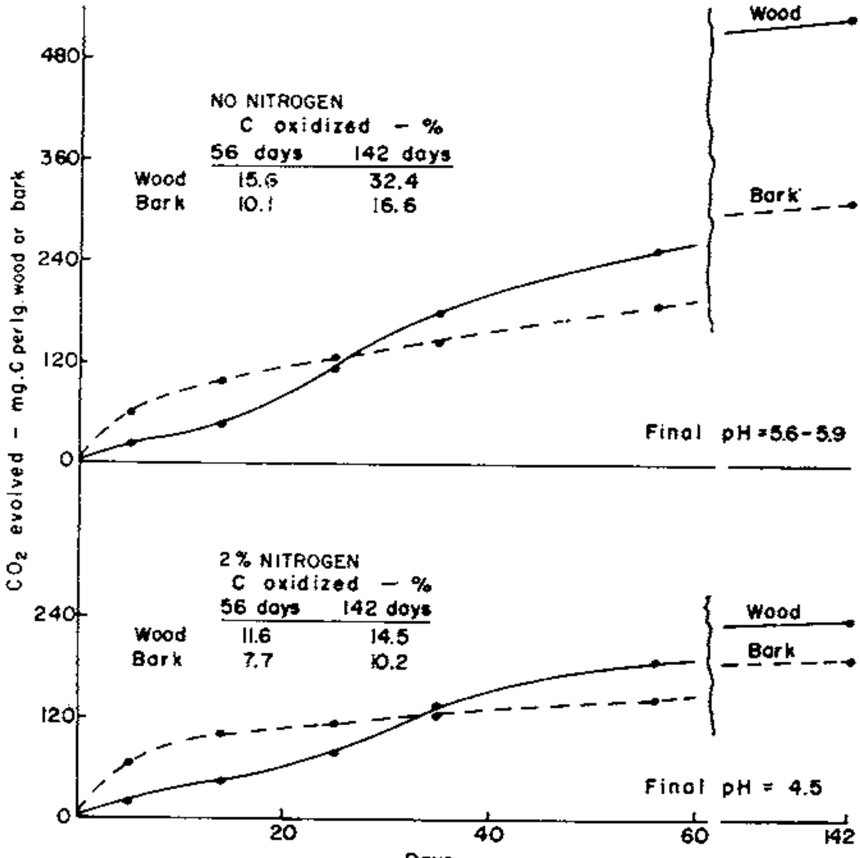

FIGURE 15.—Decomposition of white fir wood and bark in soil receiving 0.1 percent $CaCO_3$ with and without nitrogen as ammonium nitrate.

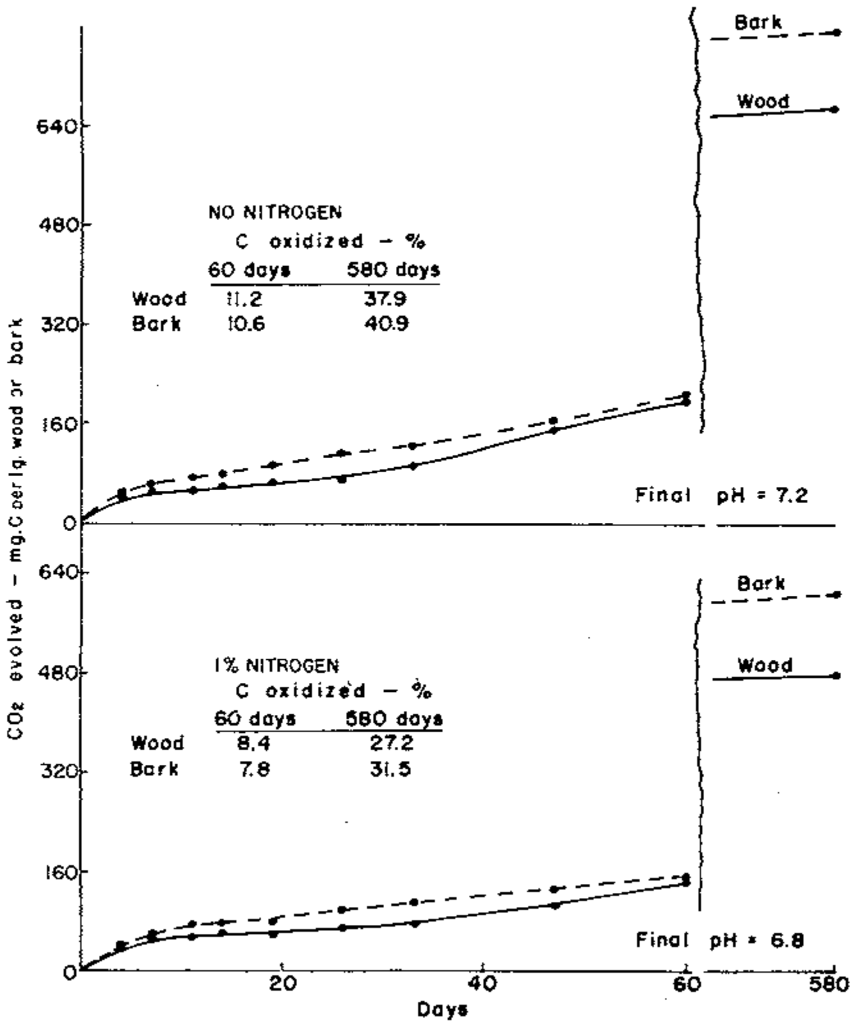

FIGURE 16.—Decomposition of Douglas-fir wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

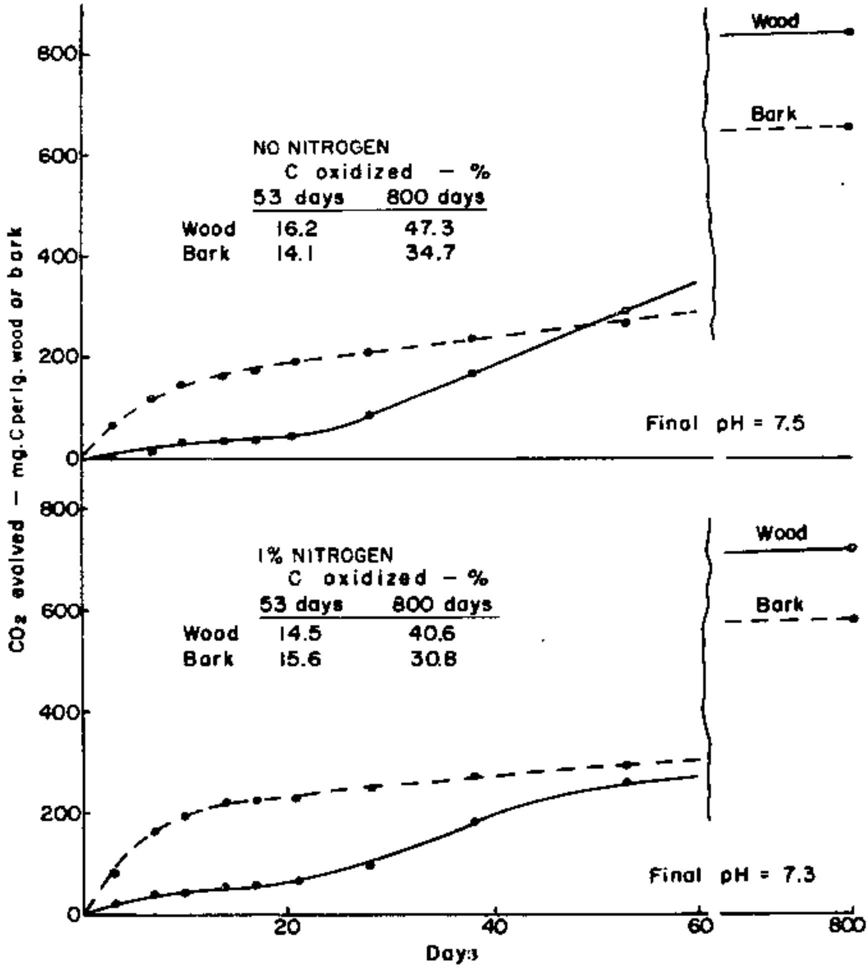

FIGURE 17.—Decomposition of Engleman spruce wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

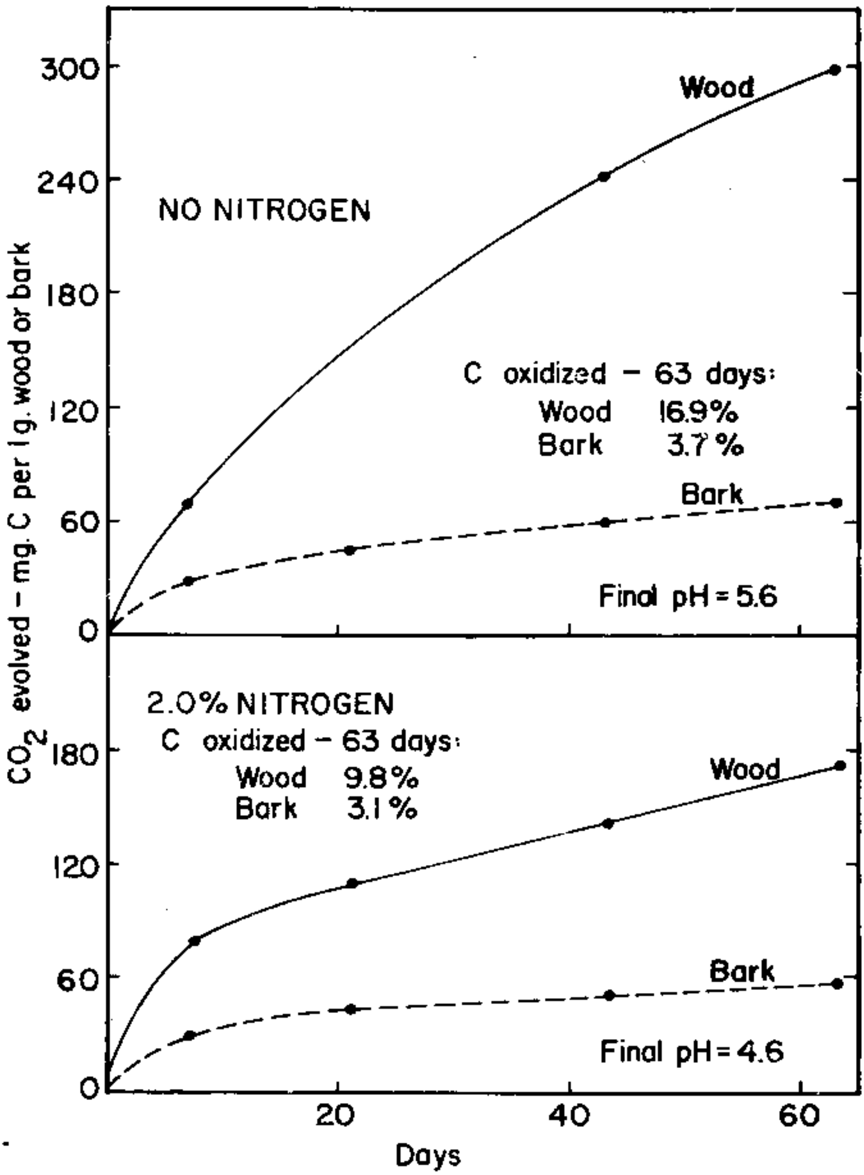

FIGURE 18.—Decomposition of white pine wood and bark in unlimed soil with and without nitrogen as ammonium nitrate.

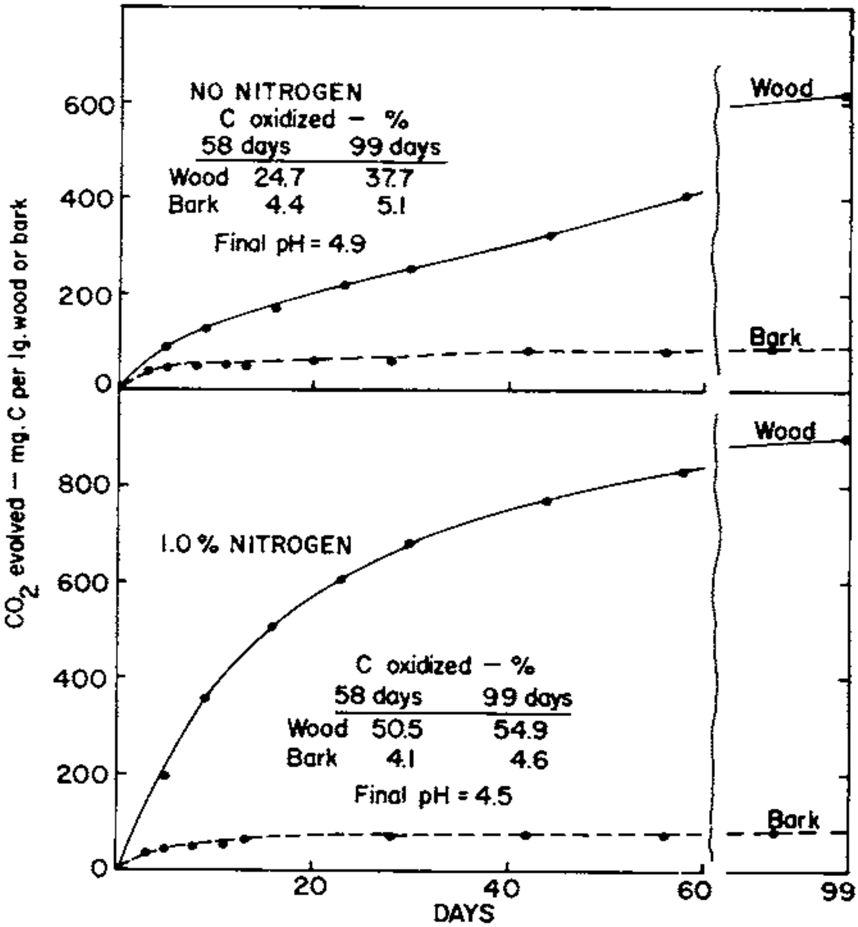

FIGURE 19.—Decomposition of shortleaf pine wood and bark in unlimed soil with and without nitrogen as ammonium nitrate.

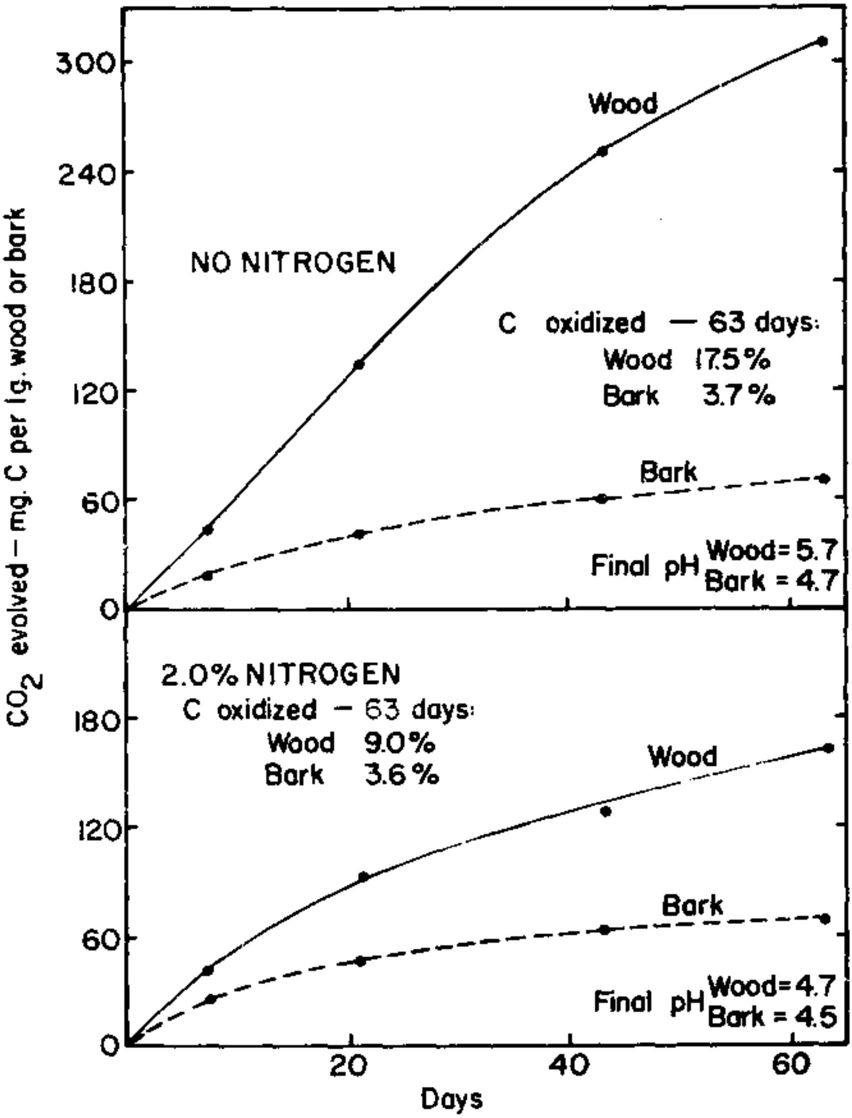

FIGURE 20.—Decomposition of loblolly pine wood and bark in unlimed soil with and without nitrogen as ammonium nitrate.

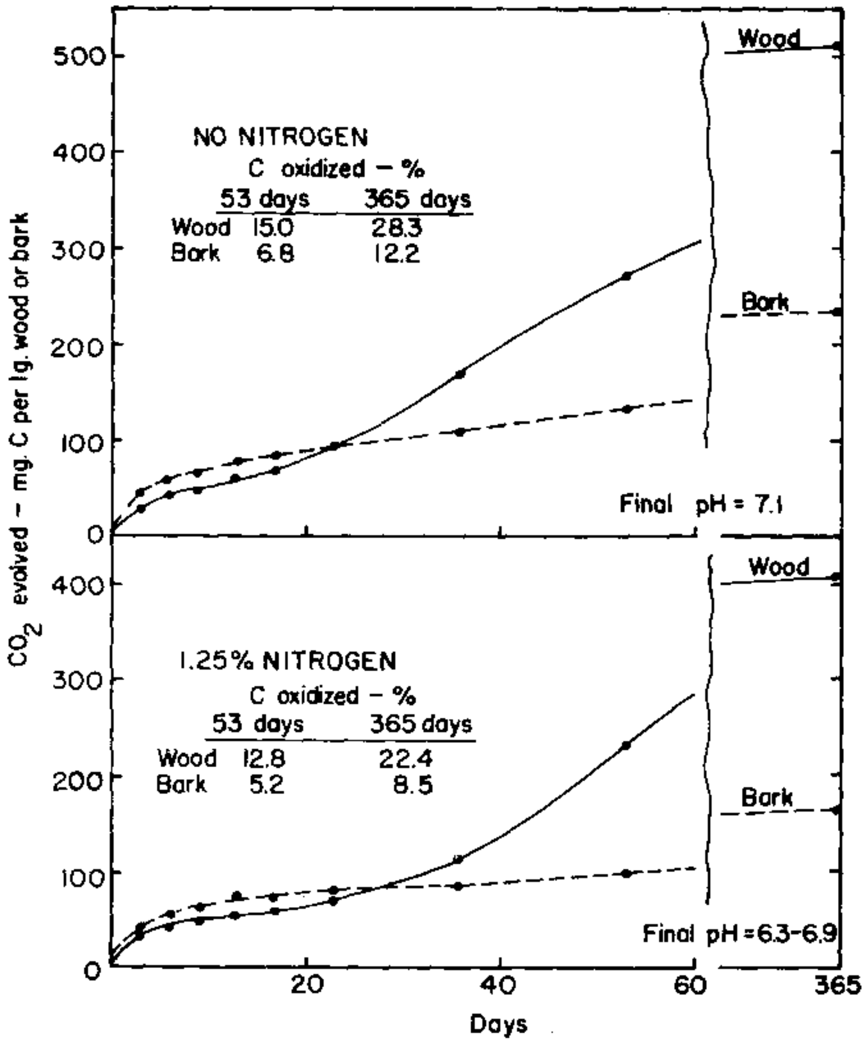

FIGURE 21.—Decomposition of slash pine wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

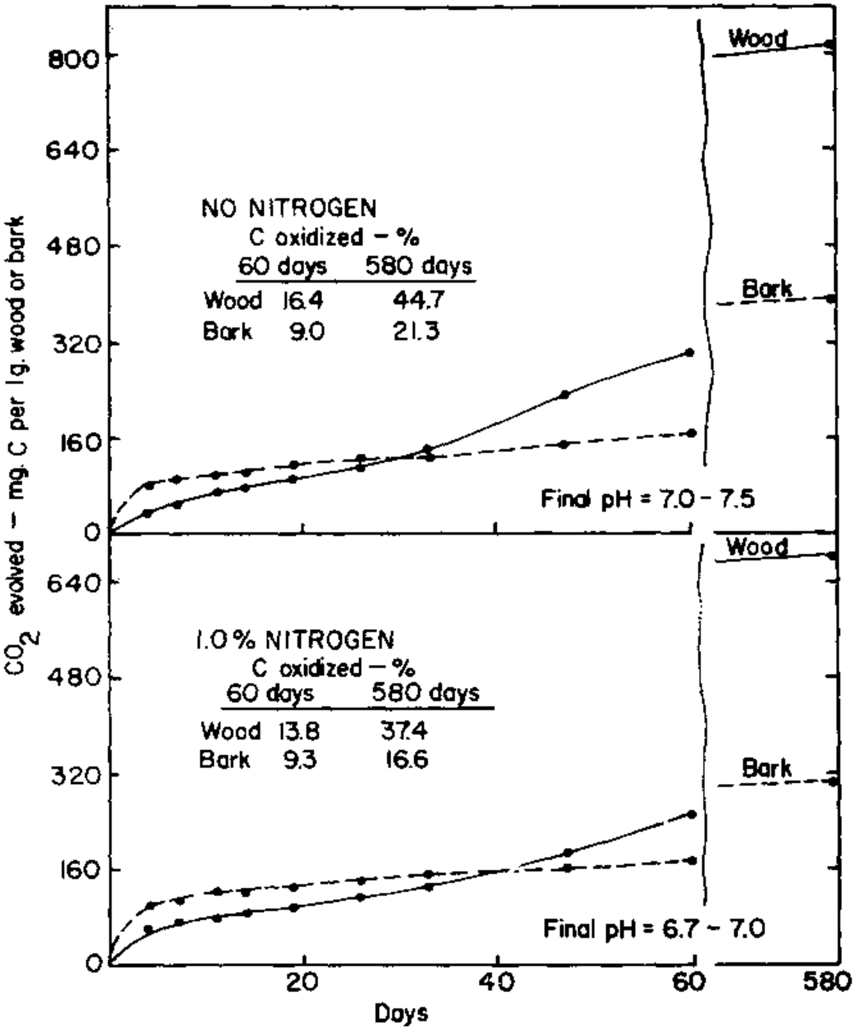

FIGURE 22.—Decomposition of longleaf pine wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

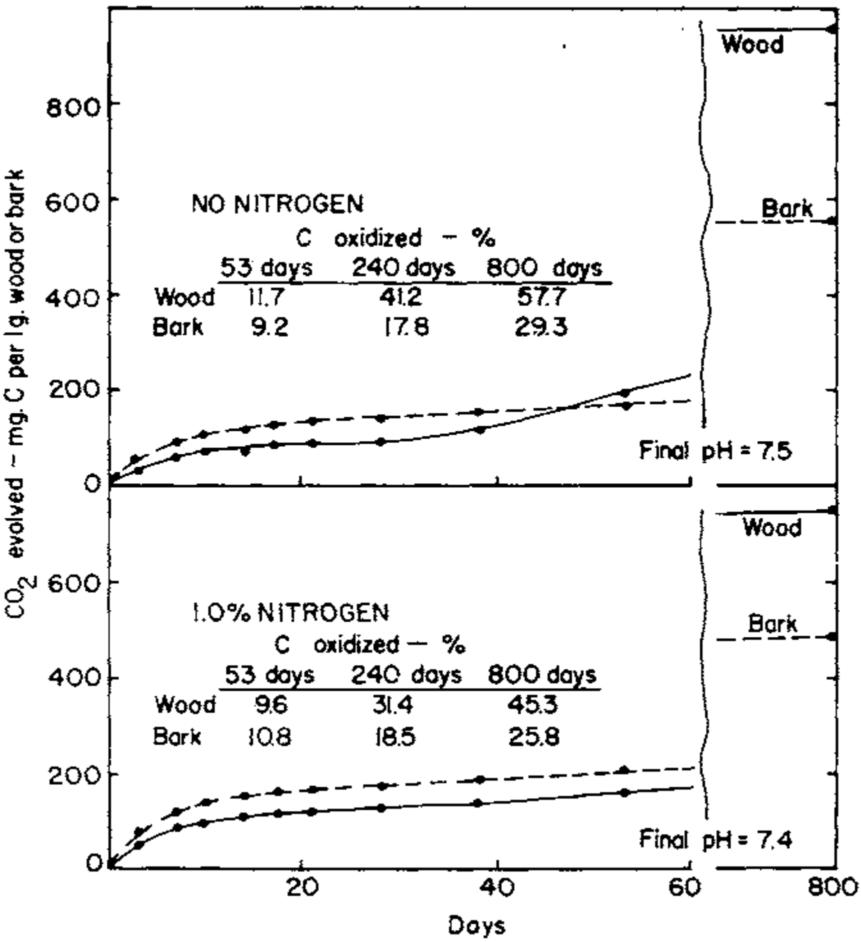

FIGURE 23.—Decomposition of Ponderosa pine wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

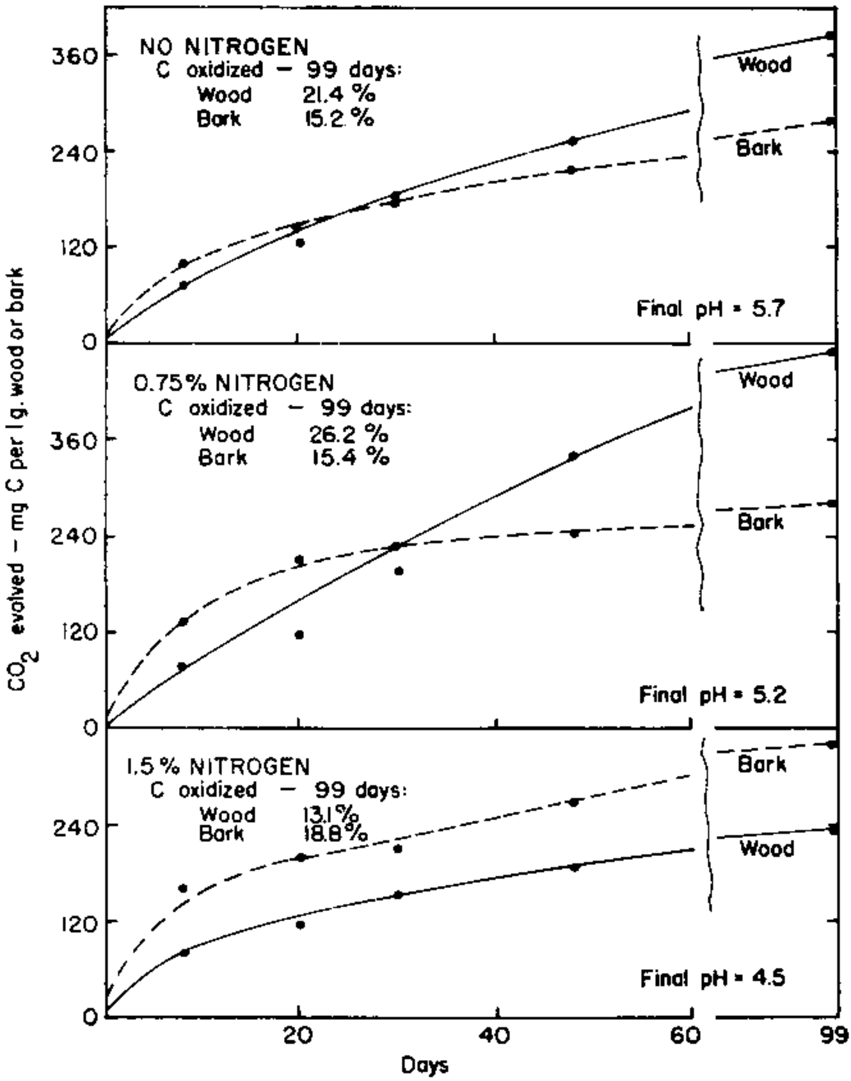

FIGURE 24.—Decomposition of western white pine wood and bark in unlimed soil at three levels of nitrogen as ammonium nitrate.

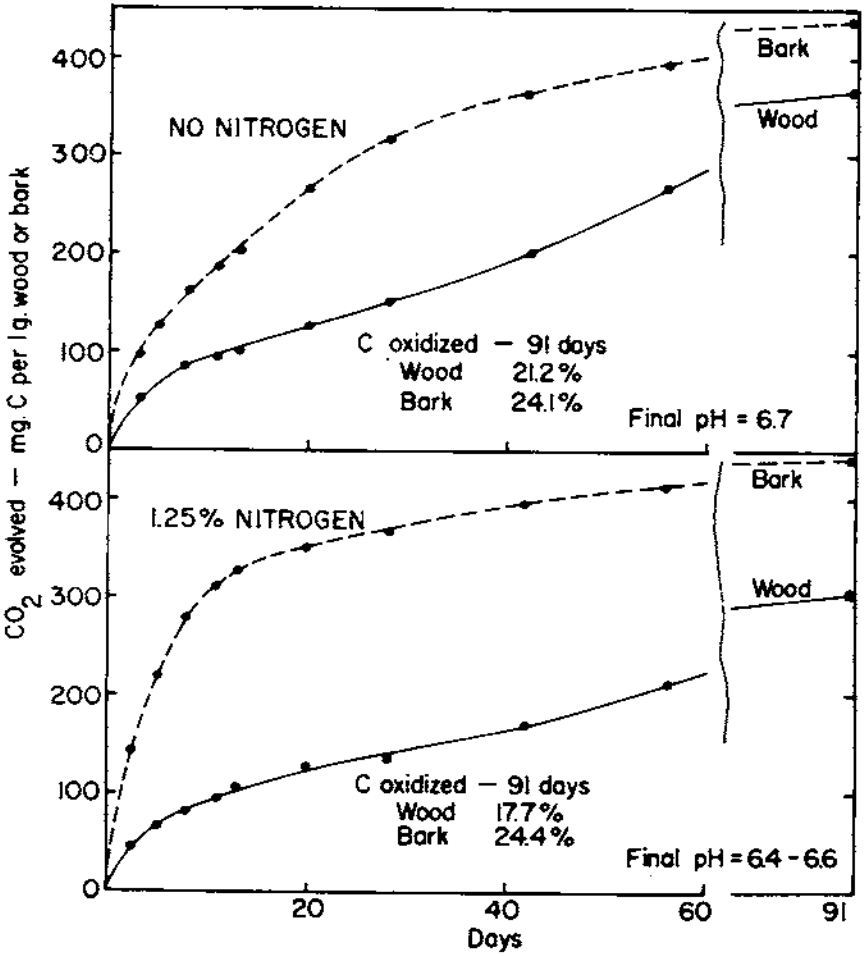

FIGURE 25.—Decomposition of lodgepole pine wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

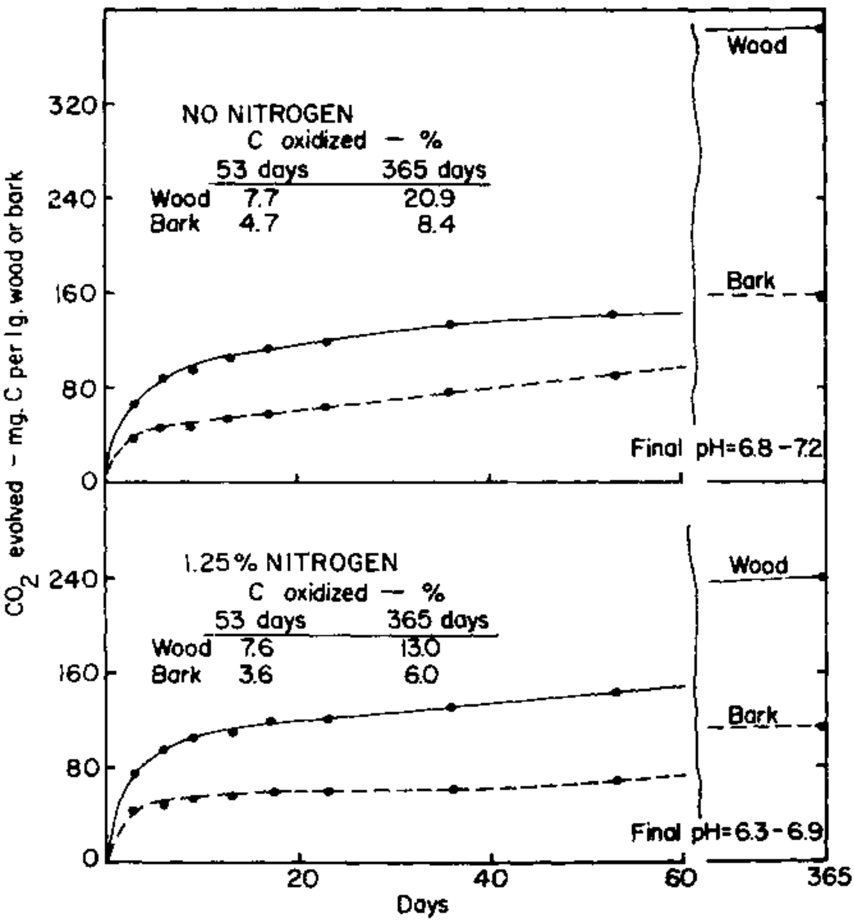

FIGURE 26.—Decomposition of sugar pine wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

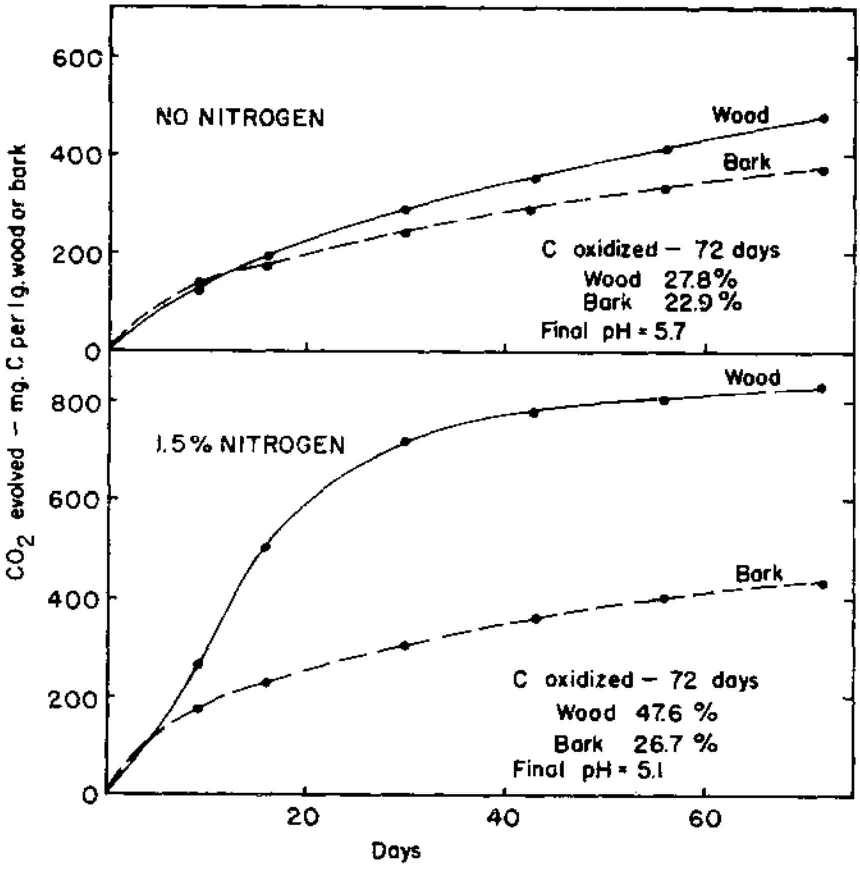

FIGURE 27.—Decomposition of black oak wood and bark in unlimed soil with and without nitrogen as ammonium nitrate.

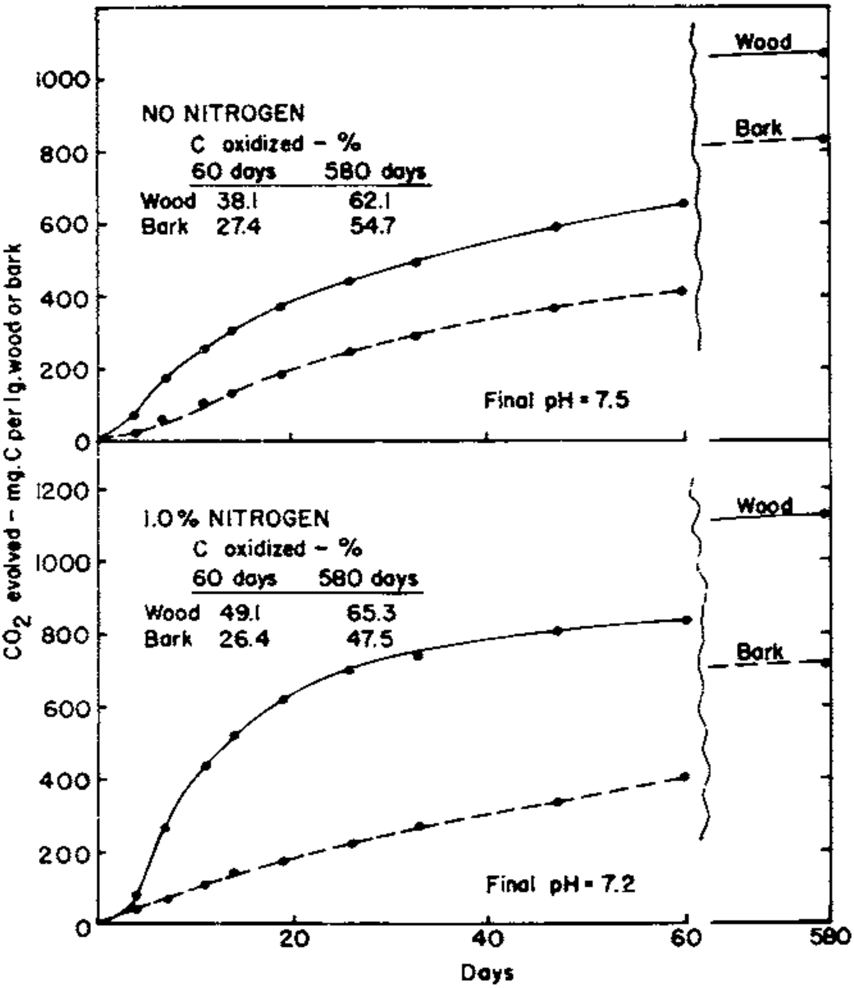

FIGURE 28.—Decomposition of white oak wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

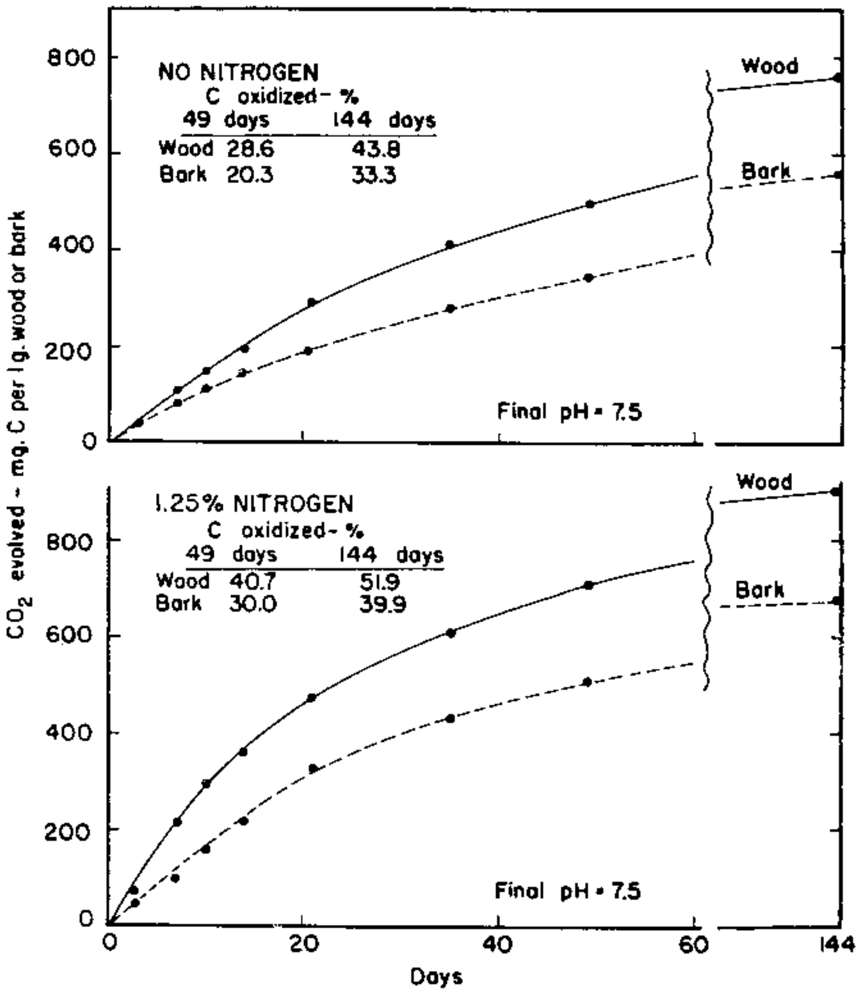

FIGURE 29.—Decomposition of red oak wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

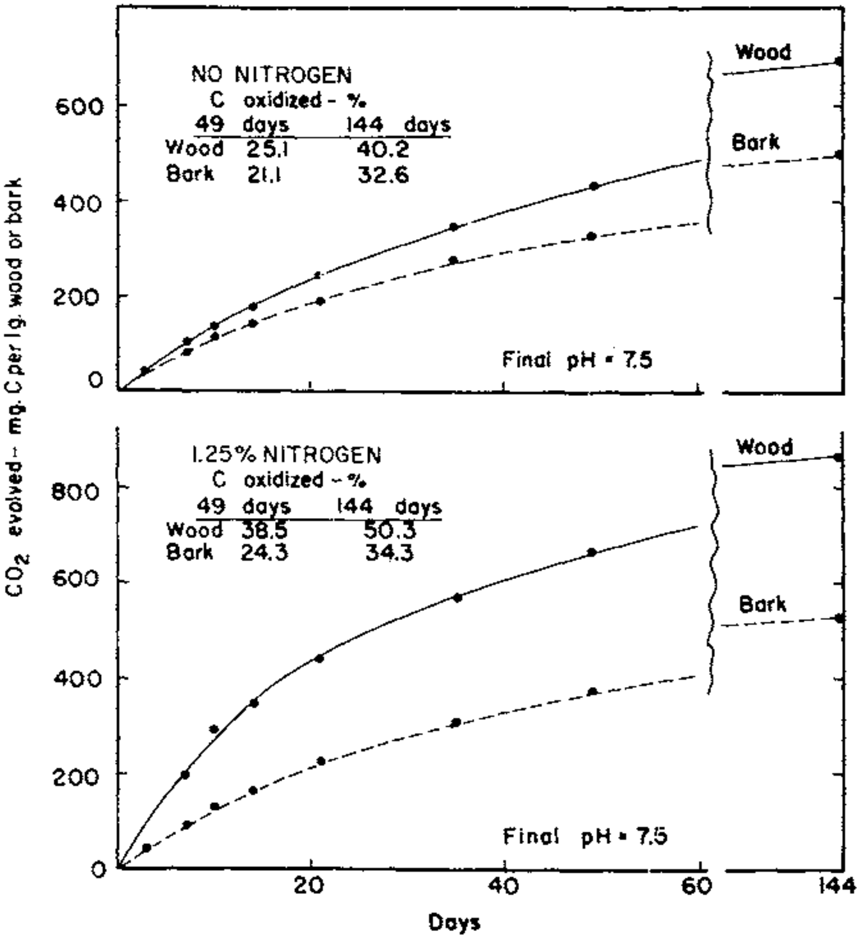

FIGURE 30.—Decomposition of post oak wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

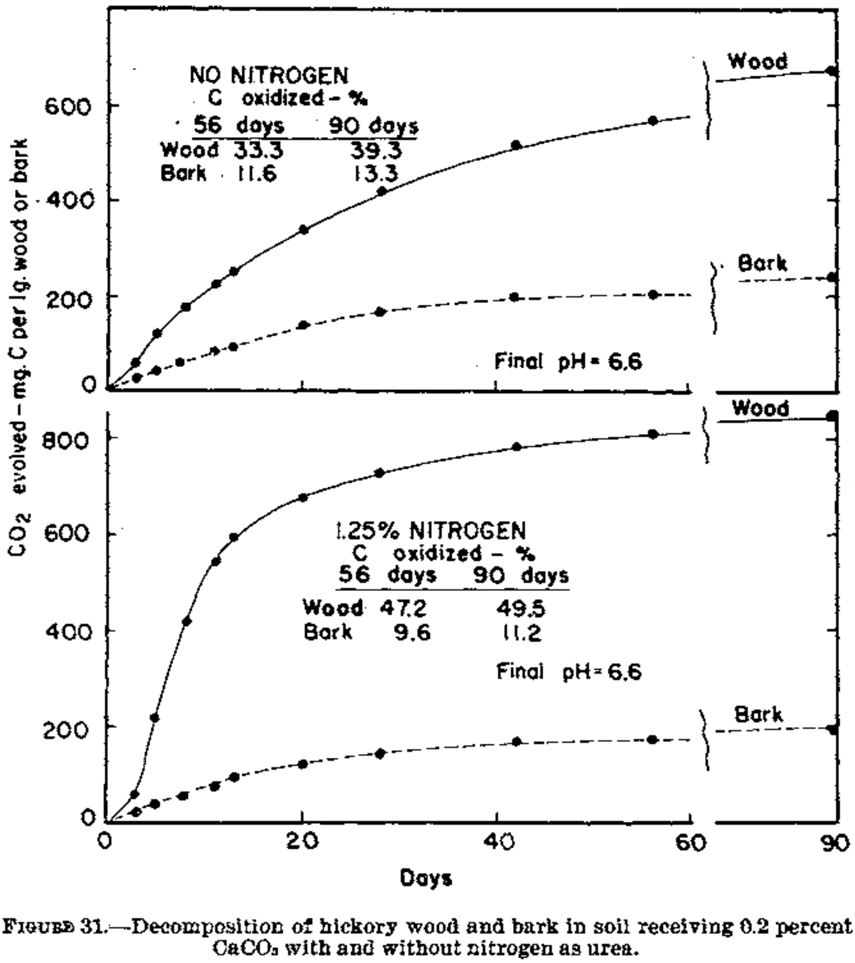

FIGURE 31.—Decomposition of hickory wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

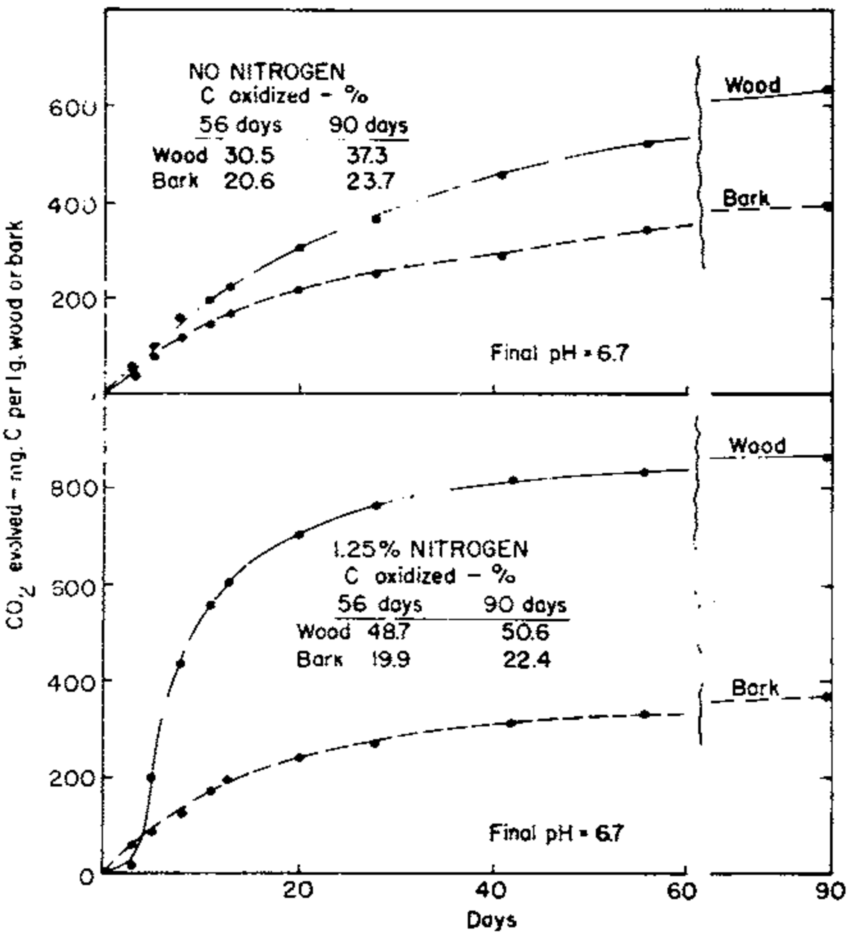

FIGURE 32.—Decomposition of red gum wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

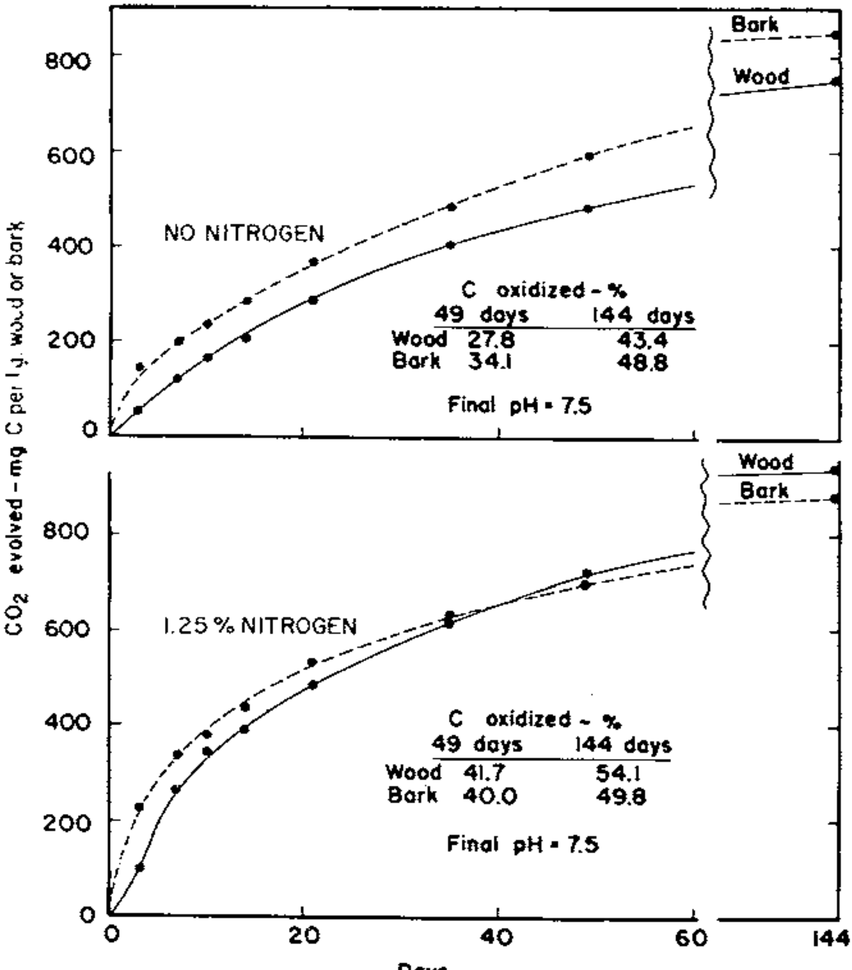

FIGURE 33.—Decomposition of yellow-poplar wood and bark in soil receiving 0.4 percent $CaCO_3$ with and without nitrogen as urea.

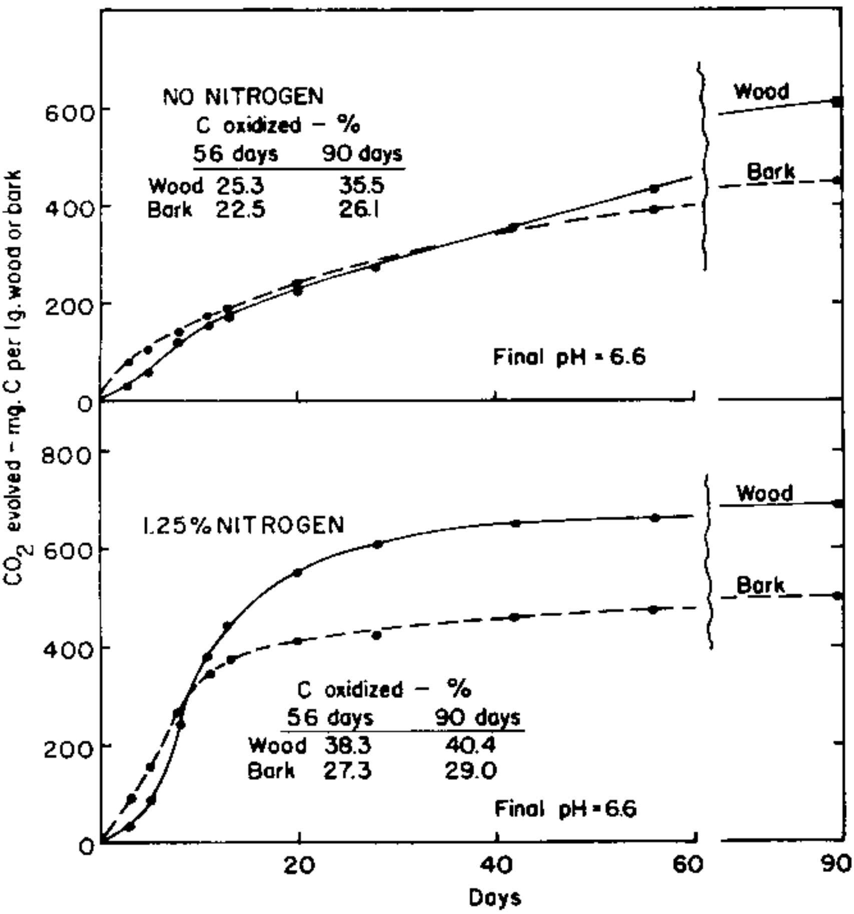

FIGURE 34.—Decomposition of chestnut wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

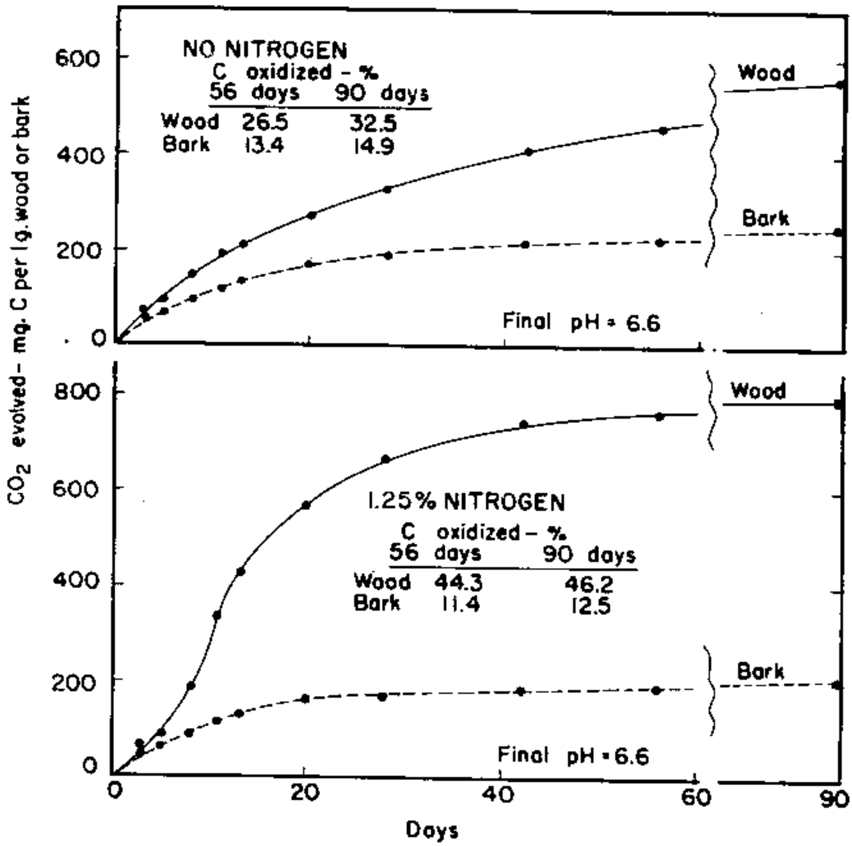

FIGURE 35.—Decomposition of black walnut wood and bark in soil receiving 0.2 percent $CaCO_3$ with and without nitrogen as urea.

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